THE EFFECTS OF ALTERNATIVE MOTOR VEHICLE REAR LIGHTING ON HEADWAY CHANGE DETECTION AND RELATIVE TRAJECTORY DISCRIMINATION BY FOLLOWING DRIVERS: A SIMULATION STUDY.

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ABSTRACT

A series of laboratory experiments were carried out to examine the effect of alternative rear light configurations on the ability of subjects to (1) detect relative motion of the vehicle carrying the lights and (2) make judgements about the trajectory of that vehicle relative to themselves. The experiments were designed to simulate the optic information presented to a driver following another car in darkness. The principle hypothesis was that light configurations which presented a substantial vertical component in addition to the usual horizontal one would enable subjects to be more sensitive in both tasks than would be the case for the traditional pair of lights.

No support was found for this hypothesis, although the size of the vertical visual angle was found to affect detection of motion, though differently at different distances, when various triangular arrays were compared to each other. There was no consistent difference between a row of three lights and a triangle, or between a row of three lights and a pair. A two- or three-light configuration was better than a single light configuration for the detection of relative motion, but a single light was better than multi-light configurations for relative trajectory discrimination.

Therefore a light configuration which includes a vertical component seems to be no more effective than the traditional pair of lights in specifying change of distance or relative trajectory of movement. However, previous research has found that such light configurations do improve sensitivity to distance change, but the conditions in those experiments were quite different to those in the current study. No previous research seems to be available with regard to the effect of such configurations on relative trajectory discrimination.

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1. INTRODUCTION

1.1 Basic Questions and chapter overview

1.1.1 Basic Questions

The amount of research that has been conducted in the area of vehicle rear lighting, rear-end collisions, and traffic flow is very large, but at the same time the spectrum of varying emphasis is broad. Individual researchers have approached the topic from a wide range of aspects; Henderson, Sivak, Olson, and Elliot (1983), in a major review of the vehicle rear lighting literature, discuss studies which focus not only on lamp spacing, number, size, colour, brightness, and mounting height, but also those considering functional separation (both via the above parameters and through others, such as combinations of flashing- and constant-light systems , with each type being for a different signalling function) and speed-indicating light systems. They also reviewed studies analysing a variety of driver characteristics (such as driver personality and effects of alcohol), as well as the role of weather and background lighting conditions in rear-end collisions.

To these we can add other studies on car-following behaviour in which the effects of rear lighting were excluded. These take the form of both following distance maintainence tasks (where, for example, the subject might be given a target intervehicle spacing and is instructed to maintain that spacing throughout a driving session) (Bierley,1963; Herman & Gardels,1963), and those involving headway change detection tasks (where the subject's task is simply to report any changes in intervehicle spacing) (Evans & Rothery,1974; Probst, Krafcyzk, & Brandt, 1987). While these studies did not involve the use of the lead vehicle's rear light system, they did demand of the subject (following driver) the same abilities (maintaining a headway and detecting changes in headway) that the lead car's rear lights are supposed to enhance. Therefore such studies are of great relevance to the vehicle rear lighting research.

It can be seen, therefore, that this area of research is both broad and of considerable depth. The research to be presented in this thesis, however, will attend to only a relatively small part of this domain. It is necessary at this point to define that part of the research before continuing.

1.1.2 Aims of the present study

The experimental work to be presented consists of a number of laboratory simulations of vehicle rear lights in darkness. These experiments were performed with a number of questions in mind:

1. A change in the spacing between vehicles can be perceived through the change and direction of change in the optical angle subtended at the eye by the leading vehicle's rear lights (Harvey & Michon,1974). Do rear light configurations having a vertical component (such as a triangular array shown on the right in Figure 1) allow a greater sensitivity in headway change detection by the following driver than do rear light configurations of the traditional type (i.e., a pair of lights, as shown on the left in Figure 1)?

2. Given that relative trajectory information is available in the symmetry or degree of asymmetry with which the image of that light configuration expands, and the movement of that light configuration in the visual field relative to the focus of expansion, does the addition of a vertical component (such as a third, high-level light) make the rear light configuration a more reliable source of information about the relative trajectory of the two vehicles (i.e. whether the following driver will strike or bypass the other car if they continue to close together and no change to steering is made)?

Thus the experiments to be described refer to two challenges facing the driver who is following another car in darkness. One is to detect as reliably and as accurately as possible any changes in headway. Whether or not the driver chooses to act on these changes is of course another matter. If rapid closure is detected, the second challenge (among many) that may face the driver is judging whether or not the vehicle in front will be struck if no alteration to steering is made. It could be the case that the following driver is on a trajectory that will result in a "near miss", or one that will be converted to a "near miss" trajectory by a small steering adjustment. There are number of reasons why "slipping around" the obstacle is preferable to braking; the latter may disrupt traffic flow, even causing a rear-end collision involving a different combination of vehicles, and requires subsequent gear changes and other corrective tasks. However, any "going around" action will be constrained by other traffic, the road's boundaries, and other obstacles. So fine and reliable judgements may be required to ensure that a "going around" action does not create more difficuties than a braking action would create.

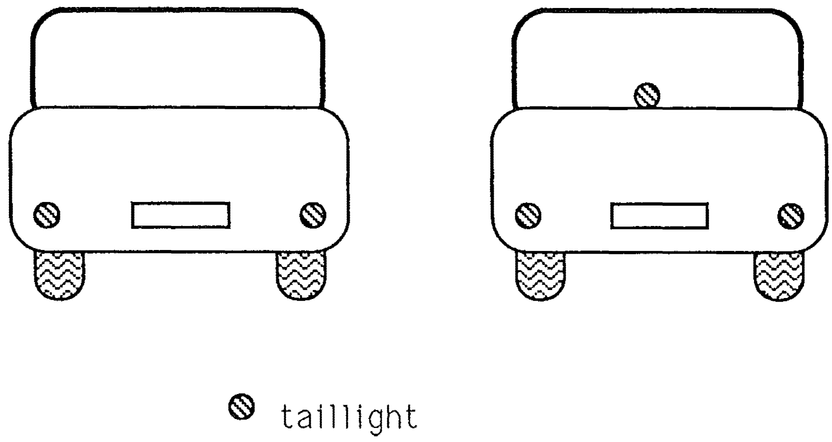


Figure 1: Conventional (left) and alternative (right) taillight configuration.

The research to be presented, therefore, was conducted with the aim of shedding some light on how differing tail/brakelight configurations may affect driver ability to detect changes in intervehicle spacing (or "headway") and to distinguish "hit" relative trajectories from "miss" relative trajectories.

1.1.3 Taillights, presence lights, and brakelights

For the purpose of this study, the terms taillight and presence light have the same meaning. While brakelights are also under analysis, the aim of the study was not to examine the effect of brakelight activation, but rather to examine the effect of information in the optic flow produced by the brakelight which has already been activated. The term rear light is intended to refer to all of the above types of light collectively.

1.1.4 Chapter overview

As indicated, there has been some research in these areas. Before reviewing this research, it is first necessary to consider literature regarding psychological processes involved in these tasks.

From this point on, the two challenges to drivers described above will be attended to seperately. The next series of sections in this chapter are concerned with the first challenge; that of detecting changes in headway and maintaining a safe headway. We begin with discussion of the two theories of detecting time-to-collision, before considering research concerned with driver ability to maintain a given intervehicle spacing, and then concluding with research on driver ability to detect a change in intervehicle spacing (headway). Having reviewed such material, the stage will then be set for an examination of the possible effects of alternative rear light configurations on headway change detection. Some studies which have been concerned with this particular topic will be discussed, as well as studies of possible relevance which have been concerned with center-high mounted brakelights. The rationale for and defining features of the experiments which were carried out as part of the current study will then be presented.

The remainder of this chapter will then be concerned with the second challenge, that of judging the relative trajectory of the lead vehicle from it's array of tail/brakelights. Relevant previous research will be reviewed, and the rationale for and defining features of the last experiment carried out in the current study will be discussed.

1.2 Time-to-collision: Ecological and cognitive hypotheses

Lee (1976) proposed a theory of braking control based on optic specification of the time-to-collision variable, which he mathematically derived as

$$\frac{\text{angular separation of any two points on the obstacle}}{\text{rate of separation of the points}}$$

or the inverse of the rate of dilation of the retinal image (p. 441). This is viewed by Lee (1980) as a higher-order optic variable, directly perceivable in the ecological or "Gibsonian" sense.

The term "any two points on the obstacle" is particularly useful in the present context as, on a motor vehicle at night, the two most readily perceivable points on that vehicle for the driver following behind are the two tail/brakelights. In fact, Janssen, Harvey, and Michon (1976) have also provided a mathematical analysis of the way in which time-to-collision is perceived, through the angular velocity of the two lights, by the following driver.

While Lee did not test his model using actual braking control experiments, there are analogous studies indicating that we use this optical specification of time-to-collision to control our movement relative to other objects. Lee (1976) quotes Spurr's (1967,1969) braking behaviour studies, in which drivers were instructed to stop at a given point on the road ahead. These studies evidently revealed deceleration patterns that resembled those that would occur if the driver was relying on optically specified time-to-collision (with the target point on the road surface) to obtain adequate but smooth braking. A later study by Lee (Lee and Reddish, 1981) analysed the velocity pattern of diving gannets, and found this pattern to resemble one that would occur if the bird was responding to the rate of optical expansion of the water surface.

However, while it is generally agreed that the driver approaching an object uses something like the time-to-collision variable, it is by no means agreed that the information is directly "registered" in the way hypothesised by Lee and others. An opposing cognitive, or computational, view is proposed by authors such as Cavallo and colleagues (Cavallo, Laya, & Laurent, 1986; Cavallo & Laurent, 1988). Because the bones of contention in this debate are of relevance to the car-following situation, some discussion of this issue is important.

Proponents of the cognitive hypothesis argue that studies on time-to-collision carried out from the ecological perspective have not necessarily, by their method, eliminated the cognitive or computational alternative. Two of the criticisms levelled against the ecological approach to perception (the 'ecological' or 'direct' approach being that which assumes that " a precise specification of the nature of objects, places, and events is available to the organism in the stimulation" (Micheals & Carello, 1981, p.9)) in general are also of relevance to the time-to-collision issue. One of these is that "direct perceptionists" have produced plausible but not necessarily the only possible or proven explanations (Haber and Hershenson, 1973). The other is that the process that appears to be "direct" may actually be one that is computational but which has become automated (in the cognitive sense) with time (or evolution), to the point where it seems (subjectively) to be "direct" (Ullman, 1980). Johansson, von Hofsten, & Jansson (1980), in allowing the study of "blind mechanical" "decoding principles" (p. 37) as a part of direct perception theory, perhaps make themselves more vulnerable to this criticism than does Gibson himself. Runeson (1977), in suggesting the concept of "smart" perceptual mechanisms for the direct perception of higher-order stimuli, opposes the idea that perception of time-to-collision or other information need necessarily involve perception and processing of basic components like distance and speed, suggesting that the apparent existence of mechanisms for the perception of lower-order stimuli may be attributable to the design of experiments which have only manipulated lower-order information. He later argued (Ullman, 1980: Peer commentary) that, while the mechanisms of perception are of interest to psychology, what we perceive is more important than how we perceive. Cutting (1986) devotes considerable space to this issue, discussing the various arguments, both historical and contemporary, that have been put forward to explain why perception only seems to be direct. Cutting attributes the concept of habitual, unconscious, and rapid judgemental processing (i.e. of the type proposed by Ullman and others) to the seventeenth century philosopher Locke, who nevertheless allowed for directness of perception in some cases (p. 226).

In reviewing the direct-indirect debate that has emerged over the centuries, Cutting lists a number of "disqualifiers" of direct perception that have been posited by the indirect perception camp. Several of these have been used in recent empirical studies to try to support the cognitive approach to time-to-collision perception. The "disqualifiers" that these researchers have searched for have been evidence of slowness and learning in perception, on the grounds that slowness of response and/or benefit from experience would be support for the computational hypothesis. While Cutting rejects both as "disqualifiers" of the direct hypothesis, the findings of these empirical studies are important.

The ecological hypothesis about detection of time-to-collision suggests that the following driver obtains this information from the rate at which the optical size of the vehicle ahead expands. The cognitive hypothesis, on the other hand, suggests that the following driver estimates time-to-collision through a calculation of distance to object/velocity (McLeod & Ross,1983). Alternatively, this can be expressed as $d_1 / ((d_1-d_2)/(t_1-t_2))$ (Cavallo & Laurent,1988),where (d_1-d_2) is the distance change in the time interval (t_1-t_2), d_1 being the initial distance and t_1 the initial point in time.

One key to deciding whether time-to-collision is directly perceived or computed by the driver would be to ascertain the effect of perceived distance to the approaching object in time-to-collision judgements. Schiff and Detwiler (1979) carried out a set of experiments to see whether stationary observers use three-dimensional information (such as actual, optically specified, distance change) rather than two-dimensional information (such as the rate of dilation of the object image) when required to judge when an object would reach them, given that three-dimensional information is available. To do this, they presented their subjects with trials in which the distance information was available as well as trials in which it was not. Results indicated that the two-dimensional information (rate of increase of object image size), rather than actual distance change information (three-dimensional) was being used.

McLeod and Ross (1983) varied the amount of time for which subjects could view a film (of the car being approached) from 2 seconds to 3, 4, 5, or 6 seconds. Their rationale was that accuracy in judging time-to-collision should improve (up to some limit) with increasing viewing time if the time-to-collision estimate involved some form of distance/velocity calculation. However, such a trend would not have necessarily provided support for the cognitive hypothesis, since longer viewing times should increase the likelihood that relative motion is detected (Harvey & Michon, 1974). In any case, viewing time was found not to affect judgement accuracy anyway. As the authors acknowledged, however, this does not necessarily rule out cognitive processing, as the computation may have been efficiently carried out within 2 seconds.

Cavallo et al. (1986, 1988) were not satisfied that McLeod and Ross (1983) had sufficiently tested the cognitive alternative to directly registered time-to-collision. Therefore they manipulated several additional factors by testing both binocular and monocular vision, comparing experienced with inexperienced drivers, and allowing either full visual field or obstacle-only vision as the subject rode in the car toward the obstacle. A number of trends in the results were seen by the authors as evidence in support of the cognitive hypothesis. Firstly, judgement of time-to-collision was more accurate under binocular than monocular viewing conditions. Since the rate of dilation of a retinal image can be perceived monocularly, the authors argued that this binocular advantage indicated the use of distance information (through binocular disparity) by subjects. Secondly, subjects were less accurate when only the object itself could be seen than when full-field vision was permitted. This suggested that subject's estimates of time-to-collision were improved when self-speed information (obtained through peripheral vision) was available. Thus these authors argue that computational processing was involved because time-to-collision estimation was improved by supplementing the basic information which specifies time-to-collision with additional optical information. However, neither of the above trends is necessarily incompatible with the ecological theory.

The authors claim further support for the cognitive hypothesis from the finding that experienced drivers were more accurate in their judgements of time to collision. While the authors acknowledge the possibility of differing decision criteria between the experienced and inexperienced groups, the finding that the visual field (full versus deprived) effect was only significant for the inexperienced subjects, even though both experienced and inexperienced drivers gained from binocular viewing, indicated that different heuristics were involved. They suggest that beginners "seem to use a method integrating speed and distance information, whereas experienced drivers seem to rely more on a method involving distance change information", adding that " the elimination of the speed parameter can be said to be very efficient" (1988, p.630), considering such problems as speed adaptation.

Cavallo et al. (1986, 1988) therefore provide some evidence to suggest that computational processes involving distance, time, and speed are involved in estimates of time-to-collision. However, as they point out, the ability of subjects to perceive time-to-collision from the image's rate of dilation alone (as opposed to when other information is also available) shows that the ecological hypothesis also has validity. It is likely, as they suggest, that the directly perceived higher-order variable described by Lee (1976) is the basic means by which time-to-collision is detected, being a basic information source which is supplemented by cognitive processing of additional information.

The issues raised in this section have considerable relevance for the experimental work that is to be presented in this thesis. The simulations done involve the subject viewing, in what is otherwise complete darkness, an array of small red lights (representing the taillights of a car) that are either stationary or moving relative to the observer. The scenario is intended to represent that of a driver (the subject) following another car down a dark rural road at night. The only information available to the subject regarding changes in headway and differences in trajectory between the two vehicles (apart from changes in the brightness of the lights, the relevance of which will be discussed later) is the rate of change of the visual angle(s) subtended by the red lights, and the symmetry/asymmetry with which the light configuration appears to expand/contract.

From these sources of information, the subject will be expected to make reliable judgements about when the "intervehicle" gap begins to change, and whether an object moving toward (in a general sense) the observer is on a collision course with them.

The subject is thus placed in what one might call a "minimal stimulus" situation, akin to that occurring in Johansson's "biological motion perception" studies (Johansson, von Hofsten, & Jansson, 1980). As such, it minimises the information (available to the observer) to the rate and pattern of change in the optic flow produced by the array of red lights. The speed and distance information required for the cognitive time-to-collision heuristic (information which, in the Cavallo studies, came from the self-motion information available from the ground around the observer) were not available to the subjects in this study.

Consequently, the experiments test higher-order, directly perceived events. They do not, by their design, test the computational hypothesis. This does not mean however that these experiments are an adventure in cue-isolation, the sort of methodology which often characterises the empiricist-transactionalist approach (Haber & Hershenson, 1973) to space perception. These experiments are aimed at the situation in which the structure of the optic flow produced by the rear lights of the lead vehicle provides the only reliable source of information about relative motion of the lead vehicle. For this reason, it seems reasonable to assume that these experiments will have external validity because they represent such a "minimal stimulus" scenario.

In conclusion then, there is evidence for both the direct perceptual and the cognitive/computational hypotheses accounting for time-to-collision perception, with most researchers concluding in favour of the direct perception model. Even Cavallo et al. (1986, 1988) in fact acknowledge the feasibility of and evidence for both, and acknowledge the predominance of the directly perceived form in emergencies and "situations where no reliable information on speed and distance is available"(p. 630). Thus the experiments to be described stem more from the ecological approach to time-to-collision perception. There are however some problems with and limitations to the concept of time-to-collision.

1.3 Time-to-collision perception: Problems and limitations

One major trend reported is that substantial underestimation of time-to-collision in simulation studies (Schiff & Detwiler, 1979; McLeod & Ross, 1983; Cavallo, Laya & Laurent, 1986; Cavallo & Laurent, 1988). This underestimation is both consistently reported and is quite substantial, with the subject's estimate being a fairly predictable proportion of the true amount. Schiff and Detwiler (1979), in their first experiment, report an understimation error of 34 to 39% (depending on the actual time-to-collision, but nevertheless being quite consistent). This trend was repeated in their subsequent experiments. McLeod and Ross (1983) report that their subjects' estimates of time-to-collision were about 60% of the true values. Cavallo et al. (1986,1988) reported that inexperienced driver's estimates were about 54% of the true amount, while experienced drivers were more accurate, making estimates averaging 72% of the true amount. Together, these estimates corresponded to 65% of the true amount. These correspond closely to the results found in the two earlier studies.

Lee's (1976) model of braking control is a feedback system based on the driver's perception of time-to-collision, as it is perceived through the rate of dilation of the retinal image of the obstacle. The abovementioned studies demonstrate a major and consistent underestimation of time-to-collision, both for stationary and moving observers. These studies of course involved passive responding by subjects under simulated or semi-simulated conditions, while Lee's model is concerned with active control of time-to-collision. It is possible that the underestimation might be less or non-existent in real world driving. Even so, is this underestimation a factor that, as a number of the above authors suggest, needs to be built into the braking control model?

The answer to this question depends of course on whether the error stems from perceiving or decision-making. Some evidence suggests that the bias occurs at the decision-making level, in particular the finding of McLeod and Ross (1983) that females underestimated time-to-collision more than did males. The authors suggested that this may be attributed to the comparative "recklessness" of male subjects in a range of decision-making tasks. By underestimating time-to-collision to a greater extent, female subjects would, if the driving task was real, be behaving in a safer manner. The fact that Cavallo and Laurent's experienced drivers made significantly higher estimates of time-to-collision (while still underestimating) than did inexperienced drivers may also be at least partly explained in terms of risk-taking; it may be the case that experienced drivers trust their perception of time-to-collision more than inexperienced drivers do. The authors argue however that this is insufficient to explain the differences between the two groups. They argue, as discussed earlier, for differing strategies for judging time to collision. McLeod and

Ross (1983) report that "a subsidiary experiment showed no evidence of any effect due to driving experience" (p. 422), but do not discuss this in any further detail. They do however use this result to discard the possibility that the effect of gender found in their study might have been due to differences between the sexes in driving experience. This does not apply in the case of Cavallo and Laurent's studies, as all subjects were male.

Nevertheless, the general finding, that people substantially underestimate time to collision, remains. While underestimation of time to collision is not a dangerous bias in a perception-action model like Lee's (being, on the contrary, a margin-of-safety bias), it is nevertheless a bias.

The second problem with Lee's model concerns the actual thresholds of motion perception. These may vary, as Janssen, Michon, and Harvey (1976) point out, among individual drivers and across different situations. It is at this level, the thresholds of and the actual detection of relative motion, that the first group of experiments in this thesis is concerned. If thresholds (both relative and absolute) can be lowered, then a driver will be able to use time-to-collision information more accurately and with less delay. Rear light configurations which support earlier detection of relative motion than do other configurations will help drivers to more effectively use such relative motion information.

Let us now consider research that deals with the task of detecting relative motion by the leading vehicle.

1.4 Parameters and visual sources of relative motion

There are four different ways in which one can describe the relative motion that occurs when two cars in a car-following situation are travelling at two different speeds. Two of these are (optically specified) physical distance measures, being more akin to a cognitive hypothesis of time-to-collision, while two are visual angular measures, being more akin to an ecological hypothesis of time-to-collision. The four can also be divided in another way, as two are velocity measures and two are displacement measures.

When describing relative motion in terms of real observer-object distance, the two measures are detectable distance change (displacement) and relative velocity (rate of change of that distance). Similarly, when describing relative motion in visual angular terms, the two measures are angular displacement and angular velocity. These four measures are quantifiable optical phenomena which may all represent the same example of relative motion, but the animal need not actually be responding to all of them, more than one of them, or even the same one(s) all of the time.

But while they may all be used to describe the same motion, the relationship between them varies as a result of the non-linear relationship between the real distance to an object and the visual angle subtended by that object. This means that individual experiments may appear to give conflicting results depending on which of the above measures are used; differences which are easily accounted for when one recalls the differing nature of the measures. For example, relative velocity and angular velocity are dependent on time, while physical and angular displacement are not. An object approaching an observer at a constant speed produces a linear distance change but an exponential change in visual angle and the rate of change of that visual angle.

An object which is displaced 10 m toward an observer produces a greater change in it's visual angle than it would if it were displaced 10 m away from the observer. Approaching objects 'loom' with increasing angular velocity while receding objects 'zoom' with decreasing angular velocity.

Given that all four of these measures can be reconciled, which should an experimenter use? Clearly distance-based analysis has a more direct relationship to the real-world problem of car-following when describing driver abilities, but the greater strength of the ecological approach to motion perception would suggest that analysis of visual angular information would be more appropriate.

In the next two sections of this chapter a number of studies will be reviewed. The first group consists of experiments concerned with driver ability to maintain a given intervehicle spacing while actually driving. These are less concerned with the actual question of thresholds of headway change, but are important in that they give some insight into whether drivers are actually using real-distance or visual-angular information. The next section, divided into two parts, is concerned with research on the actual abilities of drivers to detect changes in headway. In other words these were studies concerned directly with thresholds of headway variation. These studies vary according to whether they emphasised actual distance information or visual-angular information. Some studies were concerned with only one of the four types of information discussed above, while others consider all four. However, they are grouped according to whether they emphasise actual distance or visual angular information.

One further distinction regarding the research on headway change detection should be noted. The research can be divided on the basis of whether or not the lead vehicle (simulated or real) displayed working taillights. In some cases the "visual angle subtended" is defined in terms of the taillights, while in others it refers to the actual dimensions of the rear surface of the vehicle itself (i.e. disregarding the taillights).

One issue of relevance to both the distance-change (distal) and the angular velocity (proximal) threshold research concerns whether or not a reliable perception of the passing of time is a prerequisite for detection of motion or change in speed of an object. Time estimation is of course an integral part of a cognitive hypothesis for speed judgement. The McLeod and Ross (1983) formula for directly perceived time-to-collision takes the form of $T_c = \varnothing_1/(\varnothing_2 - \varnothing_1)\ (t_1 - t_2)$, which refers essentially to a change in the visual angle subtended by the target object in a given interval. It can be argued however that the time component exists only for the analysis of perception rather than for perception itself. Gregory (1974) disputes the need to include an "internal biological clock" (p. 449) in a hypothesis of motion perception, pointing out that neural response to a moving image on the retina may be likened to the workings of a car speedometer, in that both may work through a variable intensity signal of velocity. This approach to speed perception can be extended to the understanding of thresholds of motion and change of motion. The speedometer analogy applies equally well to these too.

Having made these distinctions, let us now address the research on detection of relative motion which has involved car-following situations (or simulations of such). Four notable studies (Hoppe & Lauer, 1951; Crosley & Allen, 1963; Potter, 1961; Mortimer, 1972) which emphasised actual distance change will be left until later in this chapter. This is because these four are by their nature more closely related to the current experiments than are most of the other studies.

1.5 Research on headway maintainence performance

Snider and Ernst (1963) carried out a field experiment involving several factors which they thought might influence the variability of a driver's speed. One of these factors was the presence or absence of a leading vehicle, so that half of the experimental conditions were car-following situations, in which the subject was instructed to try to maintain a fixed headway. Intervehicle spacing was recorded by means of a camera in the forward car which photographed the subject's car every two seconds, while the subject's car speed was recorded on an oscillograph recorder. One result of some relevance to the current thesis was that the presence or absence of a speedometer did not affect speed variation in a car-following situation. This suggests the relative insignificance of mediated self-speed information compared to the observable relative motion of the lead car.

Herman and Gardels (1963) conducted a number of field experiments and studies with regard to the "follow-the-leader" theory of traffic flow, a theory which argues that " a motorist driving along a highway behind another vehicle attempts to follow that vehicle in a stable manner" (p. 36). One of these experiments involved two cars linked tail-to-head by a piano wire which fed from a slipping clutch device, enabling the recording of the spacing between the vehicles throughout the trial. As for Snider and Ernst (1963), trials took place in daylight, but while Snider and Ernst's lead car held a constant speed, Herman and Gardels' lead car varied in speed, sometimes quite drastically. In neither study did subjects have the benefit of tail/brakelighting on the lead vehicle, but while Snider and Ernst's subjects were instructed specifically to maintain the same following distance throughout the trial, Herman and Gardels' subjects were instructed to "follow the lead car in what you consider to be a safe manner".

The results of this experiment indicated that the drivers were using relative speed information rather than actual distance to the lead car to control headway, i.e., their strategy appeared to be to try to cancel out differences in speed between the two vehicles rather than to try to maintain the target distance. Interestingly, when subjects were instructed specifically to keep at a fixed distance behind the lead vehicle (a distance indicator dial being provided to aid them in this task), their pattern of braking and accelerating became "distinctly uneven".

Herman and Gardels also varied the targeted following distance, and found that subject's sensitivity in detecting changes in headway appeared to decrease as the distance between the vehicles increased. This is not really surprising, and it will be seen in the following pages that this is a commonly reported trend. That a given change in headway should be harder to detect as initial headway is increased is to be predicted, whether one's analysis is from the point of view of a difference threshold of apparent distance or an absolute threshold of relative velocity. Herman and Gardels appear to overlook this psychophysical explanation, suggesting instead that drivers attend to the lead vehicle less when it is further away, their driving being less determined by the relative movements of the lead car when the following distance is larger. This is of course a reasonable statement in the context of the article, as these authors were looking at the overall task of smooth driving in traffic rather than the perceptual task of detecting changes in headway. It is possible that their subjects did notice the changes in headway when following distance was long but did not act on them because these changes were not imminently relevant to their driving.

Bierley (1963) employed the piano-wire apparatus used by Herman and Gardels (1963) and set his subjects the task of maintaining a spacing of 80 ft between their own car and the the leading one which, with brakelights disconnected, varied between travelling at a constant speed, accelerating, and decelerating during a trial. However, conditions were varied across two experiments such that the subjects also either viewed no aiding display at all or one of two types of aiding display (both of which were operated through the piano-wire apparatus). One of these indicated spacing between the vehicles, while the other gave both spacing and relative velocity information. Both displays were compensatory in nature, involving a guage with a needle pointer.

The results indicated that subject's reaction times did not differ between the no-display and spacing display conditions, but were significantly shorter for the velocity-aided display than for the no-display condition. This difference was greater in cases when the lead car accelerated than when it decelerated, but for all three display conditions there was no difference in reaction time between detecting acceleration and detecting deceleration by the lead car. But while the average absolute spacing error and spacing variability were reduced by both the spacing display and the spacing plus relative velocity display, the spacing plus relative velocity display reduced spacing variability by a greater amount. Furthermore, the spacing plus relative velocity display reduced the average maximum spacing change, but the spacing-only display did not. Thus relative velocity information seemed to be more effective than spacing information alone in helping drivers to maintain headways.

Gantzer and Rockwell (1967), again using a piano-wire apparatus, looked at the effect of displays providing spacing and relative velocity information on car-following performance. In this case, a red light came on if headway was decreasing beyond the acceptable "bandwidth' (which was varied in size) and a green light came on if it was increasing beyond the bandwidth. Again both spacing and relative velocity information improved subject performance. The spacing display offered over 60% reduction in headway variance at both the 70 ft and 170 ft headways, while adding the velocity display produced 47% reduction in headway variance and 58% reduction in relative velocity variance at the far distance. However the combined displays did not help drivers at the nearest following distance, which was the closest to Bierley's (1963) target distance. The authors suggest that this is because drivers can get better information through normal sensory channels at nearer distances and so tend to use artificial displays less. Nevertheless, unlike for Bierley (1963), the spacing-only display appears to have provided better information than the two-way display, but this may arise from the nature of Gantzer and Rockwell's apparatus: an on/off display which seems to be more demanding on the subject when activated for both spacing and relative velocity information (there were four lights for the two-way display).

The results of Snider and Ernst (1963) and Herman and Gardels (1963) suggest that relative velocity information is a better source of information than actual intervehicle distance information. Bierley (1963) but not Gantzer and Rockwell (1967) found that a combination of both types of information was better than spacing information only. Unfortunately, neither examined the effectiveness of a relative velocity only display, but this would have defeated their aim, which was concerned primarily with maintaining headway rather than relative velocity. Three of these studies suggest that relative velocity information enhanced performance, and the results of the fourth are possibly confounded by the type of display used. This trend of results might be interpreted as support for an ecological rather than the cognitive theory of car-following behaviour. But what are the actual thresholds of change in headway? What is the minimum change or rate of change that drivers can detect?

1.6 Thresholds of change in headway

1.6.1 Thresholds described in physical distance terms

Rockwell (1972a), on the basis of his own previous studies (not including the above reference) and work by Mortimer, suggests that the threshold for change in headway (defined as change in headway/ original headway) is between 0.1 and 0.2 (p.138). A table provided (p. 141) gives threshold changes of distance for initial headways of 50, 100, and 200 ft. These are 3, 8, and 10 ft respectively for the case of positive acceleration by the lead car, and 4,10, and 15 ft respectively for the case of negative acceleration by the lead car.

Evans and Rothery (1973, 1974) used a forced-choice procedure where subjects would receive a 4-second (and in some cases 2-second) glimpse of the lead vehicle, and were required to indicate whether it had moved toward or away from them in that interval. The lead car's deceleration and acceleration always began while the subject's vision was obstructed so that the subject didn't see any change in that vehicle's pitch. The three target headways were 125, 250, and 500 ft, and the amount of distance change during the interval was varied.

One important finding in this study was that subjects were inclined towards reporting a movement toward them, or as the authors put it, " for there to be an equal probability of positive or negative motion judgement, a positive relative motion must be present" (1974, p.166). Negative motion is motion towards the subject, a decrease in headway. This bias, which increased with increasing initial spacing, was described by the authors as a bias "in the direction of increased safety" (p. 172).

The authors conducted their analysis in several dimensions, analysing the data in terms of spacing change, initial and final spacing, relative speed, angular velocity, angular acceleration, and various combinations of these (described by the authors as "stimulus functions"). The authors suggest that if average relative speed/spacing or spacing change/spacing were taken as the stimulus function then the results took the most consistent form. The authors favoured the first because it lends itself more easily to "instantaneous" perception. Presumably "instantaneous" was intended to mean rapid.

The authors describe the results as indicating " a high level of sensitivity" (1973, p.22). Subjects could for example correctly identify (99% certainty) the direction of relative motion when the car 200 ft ahead was travelling 3 mph slower than their own. In the 4-second interval the lead vehicle would have decreased the gap by 5.56 m or 18.5 ft, which is just under 1/11th of the original distance.

Todosiev and Fenton (1966) used a simulation which presented only visual angular and angular velocity information to their subjects, but describe their results in terms of real-world distances and relative velocities. Their simulation involved using an oscilloscope in a darkened room to present the subject with two dots of light representing the rear lights of a car. The subject had to report after each exposure whether the "rear lights' had moved, and if so, whether they had moved closer together or further apart. Headways of 71, 129, 128, and 276 ft were simulated.

Thresholds of relative velocity were found to vary as a function of both simulated initial headway and viewing time. When the simulated headway was 276 ft and the viewing time was 1 second, the thresholds (75% detection) for positive and negative relative velocity were 3.4 mph and 2.4 mph respectively. The threshold relative velocities increased with decreasing viewing time and increasing initial distance. The authors propose two equations for obtaining the relative velocity thresholds (unfortunately the criterion percentage of correct detections is not stated), one for positive relative velocity;

$$\frac{1.065 \times 10^{-4}}{\text{viewing time(s)}^{0.963} \times \text{headway (ft)}^{-1.85}}$$

and one for negative relative velocity;

$$\frac{4.375 \times 10^{-5}}{\text{viewing time(s)}^{0.946} \times \text{headway(ft)}^{-1.96}}$$

Thresholds were generally higher for motion away from the subject than for motion toward the subject. The thresholds were found to be lower for simulated night-time conditions than for simulated day-time conditions (data for which was obtained in a previous experiment), but in both cases increase with decreased viewing time and increased initial distance. The authors argue that the thresholds are lower for night-time simulations because there is much less alternative information in the visual field (the daylight simulation consisted of a video showing a real car on a real road), but even the 'daylight' relative velocity threshold values obtained here are much lower than those obtained by Evans and Rothery (1973, 1974). If we consider the example given from their research, the closest parallel in the Todosiev and Fenton (1966) study is for a distance of 200 ft and a viewing time of 3 or 5 seconds in 'daylight' or 'darkness'. The threshold negative relative velocity (Todosiev & Fenton, 1966; Figure 8, p.100) was 0.58 mph for both the 3- and 5-second viewing times in daylight, and 0.4 mph and 0.35 mph in darkness for the 3- and 5-second viewing times respectively. These are very much lower thresholds than those found by Evans and Rothery, but the perceptual task was also simpler for Todosiev and Fenton's subjects, who viewed either a television or oscilloscope screen.

Harvey and Michon (1974) criticise Todosiev and Fenton for allowing the subject to see the acceleration and deceleration involved in the movement of the dots of light: the dots started and stopped moving within the period for which the subject viewed them. Harvey and Michon argue that "artificially low thresholds" were the result. This may at least partly explain why the thresholds obtained by Evans and Rothery (1974), who did not allow subjects to see the onset or end of relative motion, were very much higher.

1.6.2 Thresholds described in visual angular terms

Hoffman (1968) discusses the results obtained in Bierley's (1963) no-display conditions and the results of a study by Braunstein and Laughery (1964: cited in Hoffman, 1968), which was apparently similar to the no-display conditions in the Bierley experiments. Hoffman also refers to data for Torf and Duckstein (1966), who used an 80 ft initial spacing and a basic speed of 40 mph, and who required their subjects to respond as soon as they detected a change in the spacing between the car in which they were riding as passenger and the one ahead. The results for this study were presented as reaction-time data, but Hoffman (1968) has taken the data from all three studies and interpreted them in terms of the thresholds of changing visual angle subtended by the lead car. Because Braunstein and Laughery apparently used much larger initial headways than the other two studies, Hoffman interprets the data for that study in terms of threshold change of visual angle (angular displacement), but interprets the results of the other two in terms of angular velocity. His reason for making this distinction is that angular velocities for longer initial distances would be very small and possibly even disruptive to relative motion detection (p. 832). He argues that angular velocity information is more useful at shorter distances but angular displacement information is more useful at longer distances.

In any case, the threshold angular velocities obtained were, for Bierley (1963), 3.02 x 10^{-3} rads/sec for decreasing visual angular size and 3.15 x 10^{-3} rads/sec for increasing visual angular size (3 x 10^{-3} rads/sec is equivalent to 0.18 degrees per second). For the Torf and Duckstein (1966) study these were 4.46 x 10^{-3} rads/sec for decreasing visual angular size, and 10.24 x 10^{-3} rad/sec for increasing visual angular size. The reason for this relatively high value of 10.24 x 10^{-3} is not clear, although Torf and Duckstein (1966) themselves acknowledge the major difference in thresholds between the two directions of relative motion. However, the difference runs contrary to the findings of other studies, in that in this case increasing headway was much easier to detect than decreasing headway. The unusual explanation for this finding which was offered by the authors will be attended to in a later section of this chapter.

Torf and Duckstein (1966) also used a video simulation. The thresholds obtained for this experiment were 4.05 x 10^{-3} rads/sec for decreasing visual angular size and 5.54 x 10^{-3} rads/sec for increasing visual angular size. The difference in thresholds again favours movement away from the observer.

Hoffman provides the initial distance and detectable distance change data for these studies, and distance change Weber fractions can be derived from these. For Bierley (1963) the distance change fractions are about 0.04 for increasing headway and 0.025 for decreasing headway. For Torf and Duckstein's (1966) on-road experiment, the fractions are about 0.07 and 0.2 for increasing and decreasing headway respectively. For their video simulation, lower fractions were found: 0.056 and 0.09 for increasing and decreasing headway respectively.

As mentioned previously, Hoffman describes the thresholds from Braunstein and Laughery's data in terms of Weber-style fractions, as change in visual angle/initial visual angle. These vary slightly and appear to be slightly smaller for larger initial distances (smaller initial visual angles), but nevertheless fall into approximately equivalent values for both increases and decreases of visual angular size. The average Weber fraction derived was 0.112. Hoffman provided initial distance and detectable distance change data for this study too. For increasing headway, minimum detectable distance change ranged from 21.9 ft for an initial distance of 159 ft to 31.2 ft for an initial distance of 261 ft. For decreasing headway, they range from 15 ft for 158 ft up to 18.4 to 23 ft for 249 ft. A distance change Weber fraction of about 0.13 is obtainable from this data for increasing headway, with a fraction for decreasing headway of 0.08 to 0.09.

Harvey and Michon (1974) simulated vehicle taillights via two spots of light which were projected onto a screen. By use of mirrors, the spots could be made to move together or apart. This apparatus simulated the rear lights (1.4 m spacing) of a car moving toward or away from the subject at relative speeds ranging from 1.5 to 100 km/hr from initial distances of 25 to 1500 metres. Like Todosiev and Fenton (1966), Harvey and Michon varied the length of the interval for which subjects could view the light spots, but in this experiment the subjects were not able to see the lights while they were accelerating or decelerating. The lights were either moving at the desired speed or not moving when seen by subjects. The exposure durations ranged between 0.5 and 4 seconds. Subjects had to state after the exposure whether the lights had been moving relative to each other.

Thresholds were defined as the stimulus relative speed (km/hr) which could be detected on 73% of occasions. These thresholds were found to be lower when the lights were 'coming toward' (dilating) than when they were going away (contracting). The threshold 'relative velocity' increased with initial 'distance' (meters) and decreased with increasing exposure time. At 50 m, the threshold relative velocity for motion away from the subject was (Harvey & Michon, 1974; Figure 1, p.320) 5 km/hr for a 2-second exposure duration but 14 km/hr for a 0.5-second exposure duration. For relative motion toward the subject the corresponding threshold speeds were 3 and 10 km/hr. These are much higher thresholds than those obtained by Todosiev and Fenton (1966), but are much closer to those obtained by Evans and Rothery (1974). Note that both Harvey and Michon (1974) and Todosiev and Fenton (1966) found that thresholds decreased with increasing exposure time, but the thresholds obtained by Todosiev and Fenton (1966) are much lower. They did however both find that movement toward the subject was easier to detect than movement away from the subject (although, as will be noted in subsequent pages, this is because two spots moving apart are actually accelerating in angular velocity terms, while two spots moving together are decelerating).

However, Harvey and Michon also analysed their data in terms of angular velocity thresholds. These ranged (Harvey & Michon, 1974; Figure 3, p.321) between 0.3 mins of arc tan per second (for an initial angular separation of 7.5 min and 4 second exposure time) to 9 minutes of arc tan per sec (for an initial separation of 2 degrees and 0.5 second exposure time). While angular velocity thresholds were found to decrease with increasing exposure time, it was found that such thresholds increased with increasing initial visual angle. While the latter is an interesting result, to say that angular velocity thresholds increase with increasing visual angle is to refer to a geometrical phenomenon; when one considers the mathematical relationship between an object's actual relative velocity and the rate of change in the visual angle subtended by that object, we find that there is actually acceleration in the angular velocity for an object approaching at constant speed. The trend with regard to the threshold of relative velocity (in real distance terms) is probably of more meaning to the real world driver. It was found that (real) relative velocity thresholds decreased with increasing initial visual angular size.

Another finding was that, for " the larger initial visual angles" (p.321) (presumably 1-2 degrees), the angular velocity thresholds were higher if the light spots were moving together (i.e. the lead car was increasing the gap). This did not occur for smaller initial visual angles. However, this difference for the larger initial visual angles mostly disappears if the angular distance travelled (angular displacement) is used as the threshold variable. This is because two spots moving apart are actually accelerating in angular velocity terms, while two spots moving together are decelerating. But the overall angular displacement threshold is the same for both directions of movement. However, whereas real velocity and optical angular velocity thresholds decreased with increasing viewing time, angular displacement thresholds increased with exposure time. This is however, as the authors acknowledge (p. 324), largely the result of linkage between other variables, since for the same angular displacement to occur for a longer exposure duration, the angular velocity would have to be decreased.

In a follow-up to this study, Janssen, Michon, and Harvey, (1976) conducted a field test in which subjects rode in a car at a distance of either 160 or 320 m behind the lead car, in which the experimenter rode. The experimenter would set the desired positive or negative relative velocity using the lead car and would then switch on the taillights for one or two seconds (only the 2-second exposure was used for the 320 m distance). The four subjects had their vision occluded for most of the time but were permitted to look from a point in time two seconds before the taillights were activated.

Thresholds for this experiment turned out to be slightly lower than those found in the lab study. The authors attribute this to the warning available to the subjects (when they opened their eyes) and the availability of the lead car's silhouette in the period of about two seconds before the taillights came on. Another factor may have been that taillight size-brightness information was available to the subjects in the field test but was not available in the simulation (where the light spots never changed in size or brightnes as they moved relative to each other). The authors argue that the results of the laboratory and field studies were essentially similar given the above factors.

The authors were thus able to combine the data and give Weber fractions for thresholds of both actual relative velocity (km/hr) and visual angular dispacement. The fractions for relative velocity (for closure only) were as follows (where t = exposure time, v_{th} = threshold relative velocity (km/hr), and D = distance (m)):

(t= 0.5) $v_{th} = 0.152\ D^{1.16}$

(t= 1.0) $v_{th} = 0.079\ D^{1.18}$

(t= 2.0) $v_{th} = 0.018\ D^{1.38}$

(t= 4.0) $v_{th} = 0.017\ D^{1.37}$

If we assumed a 50 m headway, then the threshold relative velocities would (for closure) be 14.21, 7.98, 3.98, and 3.61 km/hr. At 70 m these would become 22.75, 12.89, 6.96, and 6.3 km/hr. Note that if we translate the data into values of change of distance in the time interval t then the values are approximately equivalent for a given initial distance for the 0.5-, 1.0- and 2.0-second viewing intervals. There was no improvement in performance between the 2- and 4-second viewing times for v_{th}, so the apparently much larger distance change threshold for 4-second viewing time than for the 2-second viewing time is simply a result of the lengthened fixed interval. Weber fractions of distance change are about 0.04, 0.046, 0.047, and 0.08 for the four exposure intervals for these two hypothetical distances combined. The similarity between the fraction for the 4-second interval and that obtained by Evans and Rothery (1974) is noteworthy. The Evans and Rothery fraction is slightly larger but is for 99% accuracy in subject response.

Harvey and Michon (1974) also calculated Weber fractions for angular displacement, presented in Figure 8 (p.323) of their article, based on the threshold angular distance moved (in minutes of arc), which is presented in Figure 6 of the same article. The change of visual angle/initial angle fractions vary substantially, from 0.04 for a 0.5-second viewing interval and 2 degrees initial visual angle to 0.2 for a 4-second viewing interval and a 15 min initial visual angle. These Weber fractions decreased with increasing initial angular separation, but increased with increasing exposure time (remembering that to have the same displacement over a longer interval the angular velocity must be less).

Two important points thus emerged from the work of Janssen, Michon, and Harvey. One was that whether or not a driver notices a changing headway depends in part on how long he or she looks at the lead car during a given fixation. The authors suggest (Janssen et al., 1976) that the driver only looks at the lead car for 0.5 second 'glimpses' at 3-second intervals. If this is the case, then the better performance associated with 2- and 4- second exposure times may be irrelevant. The authors acknowledge that they had little empirical basis for their claim, but Rockwell (1972b), after a series of studies on visual search patterns of drivers, suggests that driver eye movements are less than 6 degrees of travel and that 90% of observed fixations fall within +/-4 degrees of the focus of expansion. The rear of the car in front would fall neatly into this area. Rockwell suggests that the fovea is receptive to a 2 degrees circular area of the optic flow in a fixation, and that fixations range between 100 and 350 ms in duration. Given that the largest angular separation of the taillights in the Janssen, Michon, and Harvey studies was 2 degrees, we can see that the relevant fixations would actually probably be slightly shorter than these authors suggested. At shorter following distances, however, the visual angle subtended by the lead car would be much larger and would be also effective on the periphery of the retina for much if not all of the time.

The second major point to emerge from these studies was that wider initial angular separation of the lead car's taillights allowed the following driver to detect changes in headway at lower threshold levels. This suggested to the authors that taillights on cars should be as widely separated as possible, but it also suggested that conceding too great a headway can be dangerous just as conceding too small a headway can be.

The research on driver ability to detect changes in intervehicle spacing appears to have taken a new twist in recent years with the results of two experiments by Probst and others (Probst, Krafcyzk, Brandt, & Wist, 1984; Probst, 1986; Probst, Krafcyzk, & Brandt, 1987). In the first experiment, subjects drove behind a lead car and were required to press a button on detecting a change in headway. Driving at an initial headway of either 20 or 40 m, and with an initial speed for both cars of either 50 or 70 km/hr, the lead car driver would either accelerate or decelerate (the brakelights being disconnected) so as to produce a linear change in headway at several different relative velocities. In the second experiment, subjects viewed, on a 50 cm video screen, an ellipse (filled) which corresponded to the "perceptually effective" (1987, p. 310) area of the lead vehicle's rear surface. Thus the ellipse was produced in several sizes and rates of change of size, these corresponding generally to the apparent size and rates of change of size of the leading vehicle in the field experiment.

Thresholds were measured as subject reaction times in both experiments. Not unexpectedly, reaction times decreased with increasing relative velocity, but the relationship for both experiments was an exponential one, which suggests the use of angular velocity or angular displacement information rather than real relative velocity or distance information by subjects. Lower reaction times were found when the headway was being decreased than when it was being increased (although not to statistical significance). Furthermore, the reaction times were shorter overall for the shorter initial headway. There was no difference between the two absolute speeds of 50 km/hr and 70 km/hr.

However, while these basic trends occurred in both experiments, the thresholds were much lower overall for the laboratory simulation; thresholds for the field study were on average 3.27 times higher. The authors argue that this difference occurred because thresholds of relative motion in car-following are adversely affected by the optic flow which is produced by the subject's own motion, i.e. the displacement of optical flow discontinuities specific to the road surface and wider environmental features which flow around the observer. Such self-motion induced flow was not present in the laboratory. The authors argue (1984, p.538) that when subjects in the lab experiment were "simultaneously exposed to an artificial moving visual surround, which induces apparent self-motion" the thresholds were raised to the same level as in the field experiment. They argue further that the reason why the absolute speed of the vehicles did not affect thresholds in the field experiment was that both speeds were well above the 'saturation' level of global flow velocities.

It is possible that differences between the real world and the video screen (for example, the frame of reference provided by the edges of a video screen) may have accounted for some of the differences in threshold values. But the differences in threshold values are nevertheless extremely large. The claim that the global flow created by the driver's own movement should make regional flow created by the relative velocity of the lead car more difficult to detect is a logical one, especially if the experimental subject or real-world driver tries to use disocclusion/occlusion of the ground texture by the target object (car) as a source of information.

Why then did Janssen, Michon, and Harvey (1976) find no difference between their laboratory simulation and the field experiment? Probst et al. (1987) argue that thresholds of relative velocity are not so greatly affected by self-motion in night-time driving because there are fewer flowing discontinuities in the optic flow produced by self-motion in darkness. Janssen et al. (1976) conducted their field test in darkness. Probst's explanation would also account for Todosiev and Fenton's (1966) finding of lower thresholds for their nighttime simulation than for their daylight simulation.

These experiments by Probst et al. (1984,1986,1987) throw a different light on relative motion threshold research as it applies to the car-following task. They suggest that laboratory simulations will produce misleadingly good results unless the results are only generalised to the night-driving situation.

The most recent study of relevance was conducted by Haines (1989), who was concerned not with motor vehicles but with the ability of astronauts to detect relative motion of another spacecraft moving towards them. He found (using a method similar to that of Probst et al.) that the "orbiter image must expand by from 4 to 11% of it's initial size in order to be correctly perceived as having enlarged (approached)" (p. 149), with the neccessary percentage expansion decreasing with increasing initial size. Haines also employed a starfield background that moved at a right angle to the orbiter's line of travel (i.e. downwards in the frontal plane) at an angular velocity of either 0.1 or 0.3 degrees per second. Thresholds of target spacecraft movement increased as this background velocity increased. This supports the results found by Probst et al. (1984, 1986, 1987).

1.7 Major findings of the headway change detection research

1.7.1 Physical distance versus visual angular size

There are four ways of describing the visual specification of a change in intervehicle spacing: relative velocity, distance change, angular velocity, and angular displacement. Data has been provided on all of these in the literature.

Rockwell (1972) suggested a distance (intervehicle spacing) change threshold that is a Weber fraction of 0.1 to 0.2. A similar fraction emerges from the data of Evans and Rothery (1974). The fractions derived from the equations provided by Janssen, Michon, and Harvey (1976) (for the calculation of threshold relative velocities) are much lower, the fraction being about 0.04 for 0.5- to 2.0-second exposure times, but this is for nighttime conditions. The data of Bierley (1963) suggests fractions as small as 0.025 for decreasing headways. The fraction for the 4-second interval obtained by Janssen et al. (1976) is, however, closer to those obtained by Evans and Rothery (1974) (also for a 4-second interval) and Rockwell (1972), but would appear to be a misleading result in itself, for reasons discussed earlier. However, distance change fractions derived from the data of Torf and Duckstein (1966) and Braunstein and Laughery (1964) are quite close to those suggested by Rockwell.

Evans and Rothery (1974) suggested that relative velocities of less than 3mph could be detected at intervehicle spacings of 200ft or less in a viewing interval of 4 seconds. Todosiev and Fenton (1966) found very much lower thresholds, of as little as 0.58 mph for equivalent conditions simulated in the lab, but Harvey and Michon (1974) and Janssen, Harvey, and Michon (1976) found thresholds much closer to those found by Evans and Rothery.

Hoffman (1968) reported threshold angular velocities of about 3 to 4 x 10^{-3} rads/sec when the distance to the vehicle subtending that visual angle was approximately 80 ft. Harvey and Michon (1974) report threshold angular velocities ranging between 0.3 and 9 mins of arc tan, depending on exposure time and initial angular separation. These are lower (correcting for the different units of measure) thresholds than those given by Hoffman, but Hoffman was reporting on studies carried out in daylight.

Hoffman (1968) gives Weber fractions for angular displacement which are about 0.112. Fractions given by Harvey and Michon (1974) vary widely according to exposure time and initial visual angle but range between 0.04 and 0.2. Thus they found both much higher and much lower angular displacement thresholds, depending on various conditions, than those quoted by Hoffman (1968).

1.7.2 Headway change thresholds and initial distance

If the threshold is described in physical distance or relative velocity terms, the amount increases with initial distance. Since, however, larger initial distances equate to smaller visual angles, threshold angular velocities and angular displacements decrease with increasing initial distance. There does not appear to be a constant threshold angular displacement for all visual angles.

Hoffman (1968) has made the notable observation that at greater distances angular velocities will be too small to be detectable, and that angular displacement is a better source of information in these circumstances.

1.7.3 Headway change thresholds and direction of change

Thresholds are larger for relative motion away from the observer if the threshold is defined in terms of relative velocity, physical distance change, or angular velocity terms. However, the difference largely disappears if the thresholds are defined in angular displacement terms, and the difference for angular velocity stems from differences between the nature of 'zooming' and 'looming' in geometrical terms. Harvey and Michon (1974) found that the difference in angular velocity thresholds attributable to direction of movement did not occur for longer initial distances (smaller initial visual angles), which is compatible with Hoffman's (1968) suggestion that angular velocities are difficult to reliably perceive for longer distances.

Interestingly, Torf and Duckstein (1966) actually found that relative motion away from the observer was easier to detect than relative motion toward the observer. They explained this in terms of varying sensitivity across the fovea, claiming that 'zooming' involves stimulation of more sensitive areas than 'looming' for the same initial distance. This explanation is interesting but the results nevertheless conflict with the findings of most other research. Furthermore, they did not offer any empircal support for such a hypothesis.

1.7.4. Headway change thresholds and exposure duration

Both angular and real relative velocity thresholds decrease with increasing exposure time, although there is some suggestion that thresholds for exposure times larger than 0.5 to 1.0 seconds are of little significance when the visual angle subtended by the lead car is small (2 degrees or less), because of the visual search behaviour of real-world drivers. Angular displacement and distance change thresholds appeared to increase with increasing exposure duration in one study (Harvey and Michon, 1974), but this appears to be the product of a design using fixed exposure durations.

1.7.5 Headway change thresholds and the perception of the onset/end of relative motion

Todosiev and Fenton (1966), according to other authors, enabled their subjects to perceive smaller changes in simulated headway by allowing them to see the onset and end of relative motion. These researchers argue and provide evidence to the effect that relative motion is harder to detect if the acceleration and deceleration phase of the relative motion is not seen: as McBurney and Collings (1984) put it, it is easier to see that a clock hand has moved than to see it moving. Nevertheless, both types of situation have relevance to the real-world driver: sometimes the following driver will see the onset of relative motion, sometimes not.

1.7.6 Headway change thresholds, self-motion, and light conditions

Headway change thresholds seem to be lower for nighttime driving or simulation thereof than for daytime driving or simulation thereof. Also, thresholds are substantially increased by self-motion-induced optic flow. The reason for both of these trends seems to be that global flow produced by self-motion (real or simulated) competes with the regional flow produced by relative motion of the target object. Stationary observers in laboratories and drivers in darkness do not experience the same competing global flow (unless, in the case of the laboratory, it is also simulated).

1.7.7. Are drivers using actual distance or visual angular information?

Several studies of driver performance in car-following/headway maintainence tasks suggest that relative velocity information might be better than, and is certainly a supplement to, actual spacing information. However, spacing information is fundamental to the actual task; relative velocity information is of little use if the target apparent size of or distance to the lead vehicle cannot be discriminated from differing amounts of those variables.

There are however several trends in the research which suggest that drivers respond to visual angular rather than physical distance information. Firstly, motion toward the observer is easier to detect than motion away from the observer. There is no good explanation for this if we are confined to physical distance terms, but if we turn to a visual angular explanation, then there is an explanation in simple optical terms. We find that the angular displacement threshold is in fact the same for both directions of movement, but that angular velocities are greater and increase in the case of movement toward the observer, while they are smaller and decrease for motion away from the observer. Thus the visual angular hypothesis readily explains differences in thresholds due to direction of relative motion, while a physical distance hypothesis does not.

A second trend favouring the visual angular hypothesis is that thresholds were lower for real or simulated driving in darkness. If the subjects were relying on physical distance information, we would expect relative motion thresholds to be lower in daylight, when more information about distance is present.

1.8 Alternative rear light configurations and headway change detection

1.8.1. A review of studies from 1951 to 1972

We have now gained some picture of the types of headway change thresholds that have been found for the various conditions where the stimulus object has either been the rear of the lead car or it's pair of rear lights. Now it is appropriate to return to the first of two questions outlined at the beginning of this chapter: Does a tail/brakelight configuration which includes a vertical component (i.e., a triangle of red lights) afford lower headway change thresholds to the observer than the conventional pair of tail/brakelights? Note that in refering to tail/brakelights rather than just taillights, this discussion is not concerned with the information given by the onset of brakelights but the information available from them while they are activated. We are therefore considering two possible situations; that of a driver following a car in darkness where that car is displaying working taillights, and the situation, in either daylight or darkness, where the brakelights of the lead car have already been activated.

So then, do rear light configurations which include a substantial vertical component as well as the usual horizontal one afford greater sensitivity in detecting changes in headway? At least four researchers have produced evidence suggesting that this is the case.

In a very early study, Hoppe and Lauer (1951) used both field and laboratory tests to examine subjects' ability to detect the sign of relative motion of a lead vehicle, as affected by the taillight and reflector display on that vehicle. Like Janssen et al. (1976), they found that increasing the gap between the taillights improved the sensitivity of the following driver, but adding vertical visual angular information, in the form of reflective panels, improved sensitivity even further. Increasing the vertical visual angular size of these reflectors further improved performance. Reducing the subtended visual angle, either horizontally or vertically, led to higher, less accurate estimates of the actual distance to the lead vehicle.

Potter (1961) examined the effect of different shapes of reflectorised tape on depth perception, with the aim of finding out which arrangement of reflectors mounted on the rear of vehicles aided following drivers the most in avoiding collisions. Subjects viewed one of four targets (an 8.9cm vertical line, a 8.9 cm horizontal line, an 8.9 x 8.9 cm square, and a 8.9 x 1.65 cm rectangle) constructed from the tape and mounted on moving stands. A light near the subject shone onto the targets and a glare source prevented the subject from seeing anything else. The target would either move toward or away from the subject at a speed of 30 cm/second, and the subject's task was to respond on detecting movement.

As with studies described previously, motion toward the subject was easier to detect than motion away. But more importantly, movement was much easier to detect when a square or rectangle was used than when the stripes were used. Furthermore, movement by the square was easier to detect than movement by the rectangle (which was aligned horizontally).

Crosley and Allen (1966) placed subjects in a test car and drove them towards a plywood panel set up to simulate a truck's rear end. The subjects were given 0.75-second glimpses every 3 seconds. The 'truck' always had 'taillights' fixed to it (only ever appearing as a pair), but sometimes it was floodlit. The subjects were required to respond when they thought that the 'truck' (which was in fact always stationary) had 'stopped'. The subjects described the 'truck' as stopped from greater distances when it was floodlit.

However, the most important of all these studies was reported by Mortimer (1972). Beginning with a laboratory simulation, he placed subjects in a darkened room and allowed them to view (using monocular testing) a box which was initially situated 20ft from them. The box had a light source inside it and the side of the box facing the observer had holes cut in it, with red filters placed over them, to represent the taillights of a car. Three 'taillight' configurations were used; a pair of lights (aligned horizontally), an equilateral triangle of lights, and a square (slightly rectangular) array of four lights. The subject, while also performing a distraction task, was required to call out as soon as he saw the set of red lights moving. The box showing these taillights would move either toward or away from the subject from the initial 20 ft distance at a speed of 1 inch/second.

Mortimer reports lower distance change thresholds for the triangular and square arrays, and that the square array was better than the triangular array. The Weber fractions (change in distance/initial distance) were 0.17, 0.15, and 0.12 for the 2-, 3-,and 4-light arrays respectively.

Two experiments were then undertaken on the road. The first, taking place in both daylight and darkness, involved two cars travelling at a common speed of either 35 mph with 40 ft and 120 ft headways or 70 mph with 120 ft and 320 ft headways. The subjects drove the second car and, as well as carrying out the distraction task used in the laboratory experiment, were required to press a switch on detecting a change in headway (always a reduction, arising from coasting by the lead car). Since there were two initial speeds, there were two relative velocities arising from the coasting of the lead car: These were actually relative accelerations, of 3 ft/sec^2 and 1.5 ft/sec^2 for the 70 and 35 mph initial speeds respectively.

Having found a Weber fraction (distance change/ initial distance) of 0.12 (50% correct detection) for this situation, Mortimer then ran a second field test using a common speed of 55 mph and headways of 200, 300, and 400 ft in darkness. This time however, the different light configurations from the laboratory experiment were used on the lead car as presence lights (taillights). Weber fractions of 0.17, 0.15, and 0.14 were obtained for the 2-, 3-, and 4-light configurations respectively.

Mortimer's work appears to have shown that taillight configurations containing a vertical component as well as the usual horizontal component allow the following driver greater sensitivity in detecting changes in headway. Mortimer (1976) went on to reccomend the square (actually a flattish rectangular) arrangement as the best taillight configuration. He suggested a set of four blue-green lights as part of the larger presence/turn/brake light signal system which he proposed on the basis of his wider research programme.

However, with the exception of the red taillight arrrangements on coaches and some trucks, it appears that the idea has never been taken up. One reason may be that the recommended colour (blue-green) of these four taillights was not acceptable to transport authorities or car designers (posssibly because of the risk of drivers confusing them with the other blue-green signals in the driving environment). Another reason may be that the total rear light system (of which these four taillights were to be a part), which involved no less than 13 lamps of 3 different colours, was considered to expensive and complicated in terms of construction and maintainence.

Another reason why Mortimer's square array of taillights never caught on may be that, like many other devices produced by engineers and psychologists working on car-following and rear-end collisions, it was overshadowed by a simpler and readily attachable device that has become widely adopted in recent years; the center-high mounted auxiliary brakelight. This device has enjoyed considerable success in reducing rear-end collisions, and many explanations for this success have been offered. It is possible however that the phenomenon observed by Mortimer (1972) may be be related to the success of this device. When the auxiliary brakelight has been activated, it contributes to the formation of a triangle of three red lights. Thus, while the lead driver is braking (which is often for several seconds or more) the following driver is confronted with a triangle of three red lights rather than the pair of brakelights which would be displayed by a car which has no auxiliary high-mounted brakelight. Could it be the case that the triangular array of lights is allowing the following driver to make more accurate judgements about the efectiveness of his/her attempts to stop the change in headway which was initially signalled by the onset of the brakelights? If we look at the research on the auxiliary center-high mounted brakelight, we find that this possibility does not appear to have been considered.

1.8.2 The auxiliary center-high mounted brakelight as an effective accident prevention measure

The effectiveness of this device in reducing rear-end collisions has been well demonstrated. Rausch, Wong and Kirkpatrick (1982), using 900 taxis assigned to three groups, found that the experimental group cars (with either a one- or two-bulb center-high mounted brakelight added) had 44% and 58% (respectively) less rear-end collisions than control group cars over the same period (relevant rear-end collisions in such studies are defined as those in which the vehicle, having been stationary or moving forward, was struck from behind in conditions where the high-level brakelight would have been seen).

Similar results were obtained in similar field tests conducted by Malone, Kirkpatrick, Kohl, and Baker (1978) and Reilly, Kurke, and Buckenmaier (1980) (both cited in Rausch et al. (1982), Henderson et al. (1983), and Thomson (1984)) and also in a New Zealand study by McCormick and Allen (1988). An interesting additional feature of both the local study and of Malone et al. (1978) was that vehicles equipped with the auxiliary brakelight, if struck from behind, were less seriously damaged than control vehicles.

Cost-benefit analyses (McCormick & Allen, 1988; Somers & Hansen, 1984; Thomson, 1984) also strongly reccomend the use of these lights. While some of these researchers do not appear to have concerned themselves with the reasons underlying this success, the general conclusion has been that the device is successful because it is placed at a height where it is more likely to be noticed. Explanations for the importance of mounting height differ. As mentioned earlier, Rockwell (1972b) found that 90% of observed visual fixations by drivers are within +/- 4 degrees of the focus of expansion. Given that the focus of expansion is temporally closer to the observer in car-following than in open-road driving (Schiff, 1980), we can conclude that the center-high mounted brakelight is located in an area where many more fixations occur than is the case for the locations of conventional brakelights. Certainly this was what was found by Sivak, Conn, and Olson (1986), who had carried out their own study on visual search patterns of drivers following another car. The car ahead (three different vehicles being used) did not actually have a center-high mounted brake-light fitted, but fixations nevertheless were concentrated in the area where one would have been placed (i.e. the center of the rear window). The authors of this study argue that the location of the auxiliary brakelight is important because drivers tend "to look through the lead vehicle in an atttempt to gain information from further ahead" (p.21). Another possibility is that the center-high mounted brakelight falls into the line of sight of the 'relaxed eye' of the following driver. Local transport authorities (personal communications) have suggested that the effectiveness of these lights arises not only from their placement in the vehicle in front but also from their placement in vehicles further ahead in the traffic stream, whose other (conventional) brakelights are obscured by the intermediate vehicles.

However, this would seem to be only an additional advantage supplementing the main one, since these lights are also effective when there is no third vehicle ahead of the immediate lead vehicle.

While the explanations may vary in emphasis, the basic conclusion is the same; the center-high mounted brakelight is effective because of it's location. But such treatment of the brakelight question is inadequate in itself, for as Lee (1976) points out, this on/off signal provides no further information about the lead vehicle's rate of deceleration. Once the brakelights have been activated and the driver's attention drawn to them, the driver must then rely on his/her perception of the amount and direction of the relative velocity of the lead vehicle, as specified by the amount and direction of the angular velocity of the brakelights, to effectively and economically control his/her own velocity changes in restoring the traffic balance. If the triangular tail/presence light array affords better headway change sensitivity than the usual pair of taillights, then does a triangular array of brakelights (created by the addition of a center-high mounted brakelight) offer the same benefits to the following driver? If so, perhaps the auxiliary brakelight should also be a tail (presence) light.

If we want to more clearly specify the relative velocity of the lead car, there are two possible routes to take. One is to transmit deceleration information via a intensity-variable display mounted on the rear of the lead car. Examples of this have included Voedvosky's (1974) deceleration-regulated rear-mounted flasher light (the success of which appears to have been due to it's mounting height (Henderson et al., 1983), with Mortimer (1981; cited Henderson et al., 1983) finding no advantage in a deceleration-regulated flasher unit as opposed to a constant-rate flasher unit), and various multiple-light and multiple-colour lighting systems which produced different signals depending on the lead vehicle's acceleration (positive and negative) status, all of which have been reviewed by Henderson et al. (1983). However, such devices have met with little success; as Mortimer (1979; cited Henderson et al., 1983, p. 14) put it, "the results of the experiments.... indicated that such information was not particularly useful in augmenting the cues that were available from other sources to allow the drivers to achieve proper spacing and acceleration/deceleration of their vehicles". Such devices generally have two weaknesses. One is that they require cognitive association on the part of the observer in order to be effective; the observer (assuming that he/she even attends to such information in the first place) must translate the changing flashing rate, colour, or brightness of the signal lights into velocity information. The other weakness is that the information provided cannot guide the following drivers actions, as the latter's responses do not affect the display's output (the piano-wire apparati referred to earlier in this chapter did not have this problem but are of course impractical in the real world).

The other route to improving the following driver's sensitivity is to apply principles of direct perception theory to the question. The questions one would ask in taking this approach are how and why different rear light configurations might affect sensitivity to relative motion, and consequently accuracy in perceiving time-to-collision.

As described earlier, Mortimer found that a triangular or square array of tail (presence) lights was better than a pair for the purpose of detecting changes in headway. Is the triangular array of activated brakelights, now often seen as a consequence of the introduction of auxiliary, center-high mounted brakelights, better than the conventional pair of lights in the same way? This is a question which does not seem to have been addressed.

Sivak, Post, Olson, and Donohue (1981) ran an experiment in which subjects drove behind a lead car which carried nine brakelights arranged in a 3x3 grid. The experimenters could produce brakelight configurations involving 1, 2, 3, 4, or all 9 lights in a number of ways; horizontally aligned pairs, vertically aligned pairs, horizontal rows of three lights, triangles of varying 'steepness', a square, a rectangle, single lights, and all 9 lights activated together. The subjects were to respond by pressing a button when they saw the lights go on (they were normally off, being activated for periods of 3 seconds). However, no relative motion or change of headway was associated with the activation of these lights, so the subject was merely responding to the arbitrary activation of the lights. Their reaction times were significantly longer for a single light than for two lights, but there was no difference between the 2-light and the 3-, 4-, or 9-light arrays. Only a few light onsets were missed by subjects and there was no particular pattern in the unnoticed onset.

The same authors then decided to test unsuspecting drivers in real traffic. In the first experiment, one car, carrying either conventional brakelights or with either one center-high mounted brakelight or two high-mounted brakelights added (one at each side), moved into position at a given distance in front of the chosen subject. A second car moved in behind the subject's car to record velocity changes and/or brakelight activation by the subject in the 3-second interval for which the first test car's brakelights were activated. Again, however, there was no actual deceleration by the lead test car associated with the activation of the brakelights. Again, no differences were found for reaction times, but this time a substantially greater number of onsets went unnoticed by subjects. However, while the subjects confronted with the conventional brakelight system only noticed 31.4% of onsets, subjects confronted with systems featuring one and two additional brakelights responded to 54.8% and 53.2% (respectively) of onsets. A similar experiment was then run by Sivak, Olson, and Farmer (1982), but this time neither reaction time or probability of response was found to be affected by the differences between brakelight configurations.

Two out of three of these studies failed to find any difference in response probability (accuracy of detection) resulting from the addition of auxiliary brakelights, and none found any difference in reaction time, but none of these actually involved a change in headway or the onset of relative velocity. What they indicate is that real-world drivers are not just responding to the appearance of a red light; they are also responding to what the red light signals, which is a decreasing headway that the driver may not have noticed before. Thus the brakelight is not of significance unless it really does signal a change in the velocity of the car ahead.

But the question of whether this extra brakelight is of help to the following driver apart from in signalling the onset of velocity change is unanswered as yet. It has not been ascertained whether the resulting triangular brakelight array might be better than the conventional horizontal pair in enabling the following driver to perceive whether or not the spacing between the vehicles has changed or continues to change.

1.8.3 Why should the alternative array be better?

Although there are several reasons why a triangle or a square of taillights (or brakelights, if the lead car is already braking) might be better than a pair of lights for the purpose of detecting changes in headway, Mortimer (1972) did not in fact suggest any explanation, other than in broad references to increasing the 'solid angle' and 'augmenting primary cues'. Optical elevation is one source of information about distance (Matlin, 1983; McBurney & Collings, 1984), and although commonly thought of as one of the empiricist 'cues', the elevation-distance relationship is an inherent part of the Gibsonian concept of texture gradients (Haber & Hershenson, 1973; Schiff, 1980). A taillight configuration which adds a substantial vertical component might more clearly specify relative elevation, and changes to that relative elevation occuring as a result of relative movement by the vehicle towards or away from an observer. Thus adding a vertical component to the taillight configuration might not only help drivers in making initial distance judgements (and thus avoiding the trap described by Crosley and Allen (1967) of mistaking a nearby truck for a distant car) but might also aid them in detecting changes in distance.

If objects are distinguished from the ground, at least in part, by the major change in texture gradient associated with that object (Haber & Hershenson, 1973; Schiff, 1980), then a rear light array which includes a substantial vertical component would more clearly specify the vertical plane associated with the rear of the vehicle. Thus the ground /object distinction would be sharpened, which might lessen the degrading effects of self-motion induced global optic flow on detectability of the local flow produced by the relative motion of the lead vehicle. While this effect, described by Probst et al. (1984,1986,1987), is much smaller at night, object/ground distinction is also more difficult at night.

But the major way in which a triangular or square light array might improve headway sensitivity relates more directly to the matter of the visual angles subtended by sets of rear lights. The driver on the left in Figure 2 is following a car which has the usual two rear lights. He/she is thus presented with one, horizontal, visual angle subtended by these two lights. Changes to this one visual angle signal changes in headway, but the research previously discussed indicates that there are limitations to the driver's sensitivity in detecting changes to this one visual angle. However, the driver on the right in Figure 2 is confronted with a triangular array of rear lights. There are three visual angles subtended by this configuration. The second and third visual angles will change if the first does. If the angular change is around threshold level, the driver would be uncertain about whether or not change had occurred. But he or she might be less uncertain if there were two additional visual angles also changing. A triangle is also a more rigid 'whole' than a pair of lights, so there should be greater certainty with regard to whether or not the subtended visual angles are changing. This may have been what Mortimer was describing when he wrote of "increasing" the "solid angle" subtended by the lights (Mortimer,1972; p. 100).

If the driver had three (or six, in the case of a square array of lights) visual angles to rely on, would he/she respond to them equally or to one type preferentially ? If the array is square or rectangle, there are two horizontal, two vertical, and two diagonal visual angles, while if it is a triangle, there are one horizontal and two semi-vertical visual angles. Probst et al. (1987) suggest that when both horizontal and vertical types of visual angular information are available, the horizontal information will be responded to preferentially. However, the vertical visual angles may still serve a confirmation or verification function, although Probst et al. (1987) suggest (and provide evidence to the effect) that vertical visual angular velocity is harder to detect than horizontal visual angular velocity for equivalent conditions.

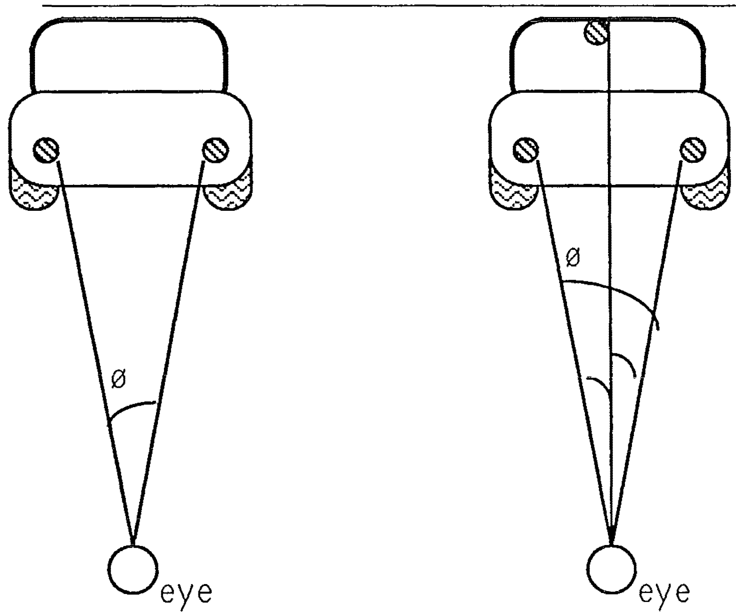


Figure 2: visual angle(s) presented by conventional rear lights (left) alternative rear lights (right)

1.9 Alternative rear light configurations and headway change detection: Unanswered questions

1.9.1 Number versus arrangement of lights

Mortimer (1972) employed lights in a pair, in a triangle, and in a square, and found progressively lower headway change thresholds for these configurations respectively. Is it possible that the decreasing thresholds were due simply to increasing frequency or density (i.e. number of lights) in the configuration? Unfortunately, Mortimer's experiment cannot provide an answer to this question because there was no condition where the same number of lights was presented but not in an array where a vertical component was added (i.e. three lights in a row instead of in a triangle). Thus it is unclear whether Mortimer (1972) lowered headway change threshold levels by adding a vertical dimension to the configuration or merely increasing the number of taillights.

1.9.2 The role of size/brightness information

When a single lamp is moved towards an observer from a great distance, it increases in brightness as it approaches while it is still perceptually a point source (i.e. of no discernable size) but reaches a distance whereafter it does not increase in brightness but does increase in discernable size (Janssen, Michon, & Harvey, 1976). This size/brightness information is of relevance to relative motion detection, as the changing size/brightness of the individual taillights of cars specifies relative motion for the observer.

Janssen (1972; cited Janssen, Michon, & Harvey, 1976) found that changing size-brightness of individual taillights is greatly inferior to the angular velocity of two taillights as a source of headway change information. But it is nevertheless a useful source of information. The 'taillights' used in Mortimer's (1972) laboratory simulation appear to have been of substantial size when viewed by the observer. Since Mortimer used real lights actually moving in depth (unlike the simulations used by other authors in which moving light dots were projected onto two-dimensional screens) there was in fact changing size/brightness information available.

It is possible that Mortimer made the task easier by adding extra lights because he improved size/brightness information, and not because he altered the spatial relationship between the available lights.

1.9.3 Relative velocity

The velocity with which the set of lights approached Mortimer's subjects in the 1/12th scale laboratory experiment was 1 inch/second. In the field study the relative velocity created involved accelerations (toward the subject) of 1.5 and 3 ft/sec^2 in the preliminary field test and 2.4 ft/sec^2 in the test where the different taillight configurations were tested. These are very slow rates of distance change. Given that the threshold distance change for the two-light array was described by a Weber fraction of 0.17 for both experiments, the time taken for the target object to travel the threshold distance would have been, for an initial distance of 20 ft in the laboratory study, 40.8 seconds. In the field study, the time taken for the lead car to complete the threshold distance change of 34 ft from the initial headway of 200 ft would be 5 seconds. The field test perhaps involves judgements made in time intervals which are sufficiently short to suggest pure motion perception, but in the laboratory study the time delay between the onset of motion and the subject's response would have been so long that it seems unlikely that the subject could actually be detecting the motion as it was happening, and was more likely to be noticing change on the basis of memory of the original apparent size of the light configuration (i.e., making a judgement as to whether displacement had occurred between observations). Thus it is possible that, in the laboratory study at least, Mortimer was studying memory for initial apparent size rather than ability to detect relative motion.

1.9.4 Mounting height of the extra light(s)

Let us assume that we have decided to test a triangular configuration of lights. Mortimer (1972) used an equilateral triangle. With this arrangement, the three visual angles subtended will be the same, as will the three angular velocities produced when there is relative motion by the car carrying them. But if threshold changes for vertically-aligned visual angles are higher (Probst, 1987), then perhaps it would be better if the two semi-vertical visual angles were initially larger, since relative velocity thresholds decrease with increasing initial visual angle. This could be achieved by making the triangle 'taller' than equilateral, done by increasing the height of the third light.

If we assume that Mortimer's findings have relevance to the brakelight configurations that are being created by the addition of an auxiliary, center-high mounted brakelight, then further questions arise. These brakelights are usually mounted in the bottom of the rear window. In this position they contribute to a triangle which is cosiderably 'flatter' than an equilateral one. In many cases, to achieve even an equilateral triangle one would have to mount this brakelight on top of the roof of the car. But doing this would defeat the original purpose of these lights, which was to provide a brake signal in the part of the following driver's visual field that is most attended to. It might nevertheless be worthwhile to see if such a high mounting position of the auxiliary brakelight offered any advantages over the usual mounting position. In any case, it might be that it is better to mount the auxiliary brakelight in the top of the rear window rather than in the bottom of the rear window (as is often the case), so that this brakelight is still in the optimal area for the purpose of conspicuity but also contributes to better relative motion sensitivity by providing a 'steeper' triangle of lights.

1.10 The rationale for Experiments 1(a)-2(b)

The basic aim of the first set of experiments presented in this thesis, in Chapters 2 and 3, was to ascertain whether rear light configurations which included both a substantial horizontal and a substantial vertical component allowed subjects to detect smaller changes in distance than those which only subtended a horizontal visual angle.

Several predictions were made;

1. Motion by a target vehicle displaying three lights in a triangle would be easier to detect than motion by a target vehicle displaying a horizontally aligned pair of taillights.

2. Motion by a target vehicle displaying three lights in a triangle would be easier to detect than motion by a target vehicle displaying a horizontal row of three lights, i.e., any improvement in headway change sensitivity should be due to the spatial arrangement rather than just the number of lights in a configuration.

3. Motion by a target vehicle carrying only one light, and thus only offering size/brightness information, would be more difficult to detect than motion by vehicles carrying two or more lights, which offer both size/brightness and visual angular information (the size of the lights used being too small to offer substantial visual angles or noticable changes to them arising from motion relative to the observer).

4. Triangles of lights which are 'taller' than others should afford greater headway change sensitivity to subjects.

Thus, across Experiments 1(a), 1(b), 2(a), and 2(b) a number of factors were manipulated. A total of six light configurations were created, and different combinations of these were tried across the various experiments. Different initial distances and both directions (toward/away) of relative motion were tested. It was expected that the results would support the usual trends of thresholds increasing with initial distance and motion being easier to detect when it was toward the subject than when it was away from the subject. What was expected however was that differences attributable to differences between light configurations would emerge over these trends.

1.11 Defining Features of Experiments 1(a)-2(b)

1.11.1 Laboratory simulations, stationary subjects

It was decided that a laboratory simulation would be used with stationary subjects viewing a target vehicle moving toward or away from them in a darkened environment. While simulations involving stationary observers have been shown to produce lower thresholds of distance change than on-road field experiments done in daylight (Probst et al., 1984, 1986, 1987), it was decided that a laboratory simulation was acceptable because it was intended to represent nighttime driving conditions.

1.11.2 Monocular vision conditions

Because actual depth was a a part of the simulation, and because the simulation was scaled down by a factor of 25 from real-world conditions, it was decided to allow only monocular viewing. Otherwise the performance of subjects might have been superficially good because of binocular disparity information which would be very useful at the short actual distances used in the simulation but not at the longer real-world distances that the simulation was meant to represent. Mortimer (1972) had also used monocular testing.

One group of subjects in one experiment was permitted to have binocular viewing. This was done to test the assumption that these subjects would perform better than the others if the scaling-down was effective in monocular terms.

1.11.3 Generalisability

The simulation was intended to represent two possible scenarios, both of which involve following another vehicle in darkness. In one case, the driver is viewing the taillights of the lead car and needs to detect any change in headway. In the other, the brakelights of the lead car have been activated for some time and the second driver needs to know whether he/she has cancelled out the changing of headway caused by the braking of the lead vehicle.

1.11.4 Availability of the onset of motion and absence of a distraction task

Unlike several of the studies refered to earlier, subjects in these experiments were able to see the onset of the target vehicle's relative motion. The vehicle's relative velocity was always zero at first, and the subject's task was to respond as soon as he/she saw it moving.

While some authors have argued that thresholds are lowered if subjects are permitted to see the onset of motion, it is also a fact that in the real world drivers will often be looking at the lead car as relative motion begins. Let us assume, for example, that the following driver has seen the lead car's brakelights come on and is now correcting his/her own velocity on the basis of the angular velocity of those brakelights. He or she is trying to reduce that angular velocity to zero. The driver in the lead car had only been braking gently at first, but (as so often happens) has reassessed the situation and has increased pressure on the brake pedal. However, since the brakelights were already on, the only way the driver behind can detect this change is through the sudden increase in the rate of change of the visual angle subtended by the set of brakelights.

However, sometimes drivers will not be looking at the lead vehicle when the the onset of relative motion occurs. What is the best way to simulate both possibilties? One is to provide the subject with a distraction task, but this can be quite artificial. The other possibility, and the one taken up in these experiments, is to randomly vary the duration of the event segment between the beginning of a trial and the onset of relative motion. The effect of this on the subject is that he or she spends less time than might be the case fixating on the lights of the target vehicle. Like the driver who is following another car along a lonely road at night, attention soon begins to wander.

Admittedly, this means acknowledging a variable which cannot be controlled with the available methods. However it was hoped that, through a repeated-measures design, the effect of this variable would be constant across all conditions for subjects.

1.11.5 The speed of relative motion

It was decided that a much higher relative velocity than that used by Mortimer (1972) would be used in these experiments, to ensure that any effects obtained were less concerned with memory for apparent size and more concerned with perception of motion as it occurs.

1.11.6 Triangles but not squares

Although Mortimer (1972) had found that a square array was more effective than a triangle, it was decided that the current study would only examine triangular arrays in comparison to conventional ones. There were several reasons for this.

One was that the triangular arrays were sufficent to test the theoretical assumptions and hypotheses which have been outlined. Secondly, since a triangle has only one more light than a pair, any differences found are less likely to be due to density or frequency of lights than would be the case if square light arrays were tested.

The third reason concerns the issue of high-level brakelights. Malone et al. (1978; cited by Henderson et al., 1983) found that rear-end collisions were reduced by a center-high mounted brakelight but not by two such lights placed on the outer edges of the top of the car's trunk. This may be because these lights were not placed in the critical 'line of sight' which many authors suggest. Therefore, it may be less relevant to consider the effectiveness of a square array of brakelights (if not taillights) if the initial main purpose of increased noticability is not achieved by this array.

1.11.7 The dependent variable

Of the many possible dependent variables available, minimum detectable distance change was adopted for several reasons. One was that a displacement measure would be more accurate than a velocity measure given the equipment to be used. The second was that most of the light configurations subtended the same largest possible visual angle, which made analysis in visual angular terms less meaningful. The third reason was that distance change as a measure relates more than any of the other measures to the real problem for drivers, i.e., how much change in headway will occur before the driver notices it changing.

1.12 Interim chapter summary

So far in this chapter we have examined the driver's problem of detecting relative motion by the leading car and maintaining a given following distance behind that car. There are two theories of time-to-collision, of which the ecological hypothesis appears to be the prefered and the best substantiated. It is also the more relevant hypothesis with regard to the situation of driving in darkness. But perception of time-to-collision depends on sensitivity to relative optical motion or relative optical velocity and changes thereof. It is possible that relative motion sensitivity can be improved by altering the rear light configurations on cars so that they include a substantial vertical visual angle as well as a substantial horizontal visual angle. The set of experiments which are described in Chapters 2 and 3 were designed to provide further information on this topic.

1.13 Discrimination of relative trajectories of other vehicles

The remainder of this chapter is concerned with a very different question to that discussed so far. The topic of interest now is the second question asked at the beginning of this chapter: do tail/brakelight configurations which include a substantial vertical component enable drivers to more accurately discriminate between a trajectory which will carry them to one side of the vehicle in front and one which will end in a collision? Let us assume for example that the lead car has braked and the following driver is now closing rapidly on the rear of that car. He/she might decide that it is neccessary or easier to try to 'go around' that car rather than to try to stop (or sufficently slow down) behind it. He or she must then be on or adjust to a trajectory relative to the lead vehicle which will carry him or her to one side of that vehicle. Unfortunately, our driver cannot always allow as much room for error as he or she might like, since environmental constraints (such as oncoming traffic and pedestrians) often reduce the available gaps considerably. Therefore this driver often needs to adopt a trajectory which results in a very near miss.

Obviously in such a situation the driver's ability to discriminate between a 'near miss' and a 'glancing blow' trajectory may be critical. What sources of information is this discrimination based on? One is the symmetry or asymmetry with which the optical discontinuities specific to the rear of the lead car (or simply the array of red lights, if at night) expand on the retina. If the discontinuities expand symmetrically, then the observer is on a collision course with the object (Haber and Hershenson, 1973; Schiff, 1980). If the looming is asymmetrical, however, then the object approaching, or being approached, is not on a collision course. However, certain smaller asymmetries also arise from a relative trajectory which will result in a 'glancing blow', so the problem is really one of discriminating a safe from an unsafe degree of asymmetry in the expansion of the optical discontinuities specific to the object.

Another source of information is the motion of the object (or parts thereof) in the optic flow relative to the focus of expansion. One way of avoiding a collision is to keep the object outside the center of the flow field, or the point from which all the flow vectors originate. Gibson's (1979, p.233) rule for steering during locomotion is this: "To steer, keep the center of outflow outside the patches of the array that specify barriers and within a patch that specifies an opening". The focus of expansion thus specifies where one is heading, so objects which stay in that region as they expand (optically) are ones which the observer is approaching directly (Micheals and Carello, 1981).

Drivers appear to be reasonably accurate at discriminating between 'hit' and 'miss' trajectories, but there is evidence to suggest that this ability has it's limitations. Helander (1978) produced results of some social concern with an experiment in which drivers' steering behaviour was recorded as they drove along both windy and straight roads. He found that drivers were turning the steering wheel about 1 degree towards an oncoming car about two seconds before passing it. This would peak just as they passed that car. The drivers also turned the steering wheel towards cyclists and pedestrians on their own side of the road. Helander labelled this phenomenon 'perceptual tropism', arguing that drivers steer towards objects of 'perceptual significance'. However Triggs (1981) and Summala, Leino, and Vierimaa (1981), observing actual vehicle displacement rather than steering wheel movements, found that cars actually move away, laterally, from oncoming vehicles. Both argue that what is actually happening is that drivers are allowing a safety margin by slightly increasing the lateral gap as they approach oncoming vehicles (perhaps by not correcting for the car's "float" away from the oncoming car's path), and that what Helander found was the corrective steering adjustment for this avoidance behaviour (a corrective response, to a previous gradual increase in lateral gap, which presumably occurs when the driver is certain, unconsciously it would seem, that a collision will not occur).

What these three studies suggest is that drivers are by no means perfectly accurate in discriminating 'hit' from 'miss' trajectories. Knowingly or not, they allow themselves a margin of safety in what would seem to obviously be a non-collision course situation.

1.14 Limits to ability: Discriminating 'hit' from 'miss' trajectories

There has been some research into the topic of how we perceive heading during locomotion, and how sensitive we are to changes in that heading. Many of these studies are reviewed by Cutting (1986) and Warren, Morris, and Kalish (1988). Many of them are of little relevance to the question at hand, since displays of random-dot surfaces were often used, while in other cases objects of meaningful dimensions served only as sources of information about heading in the overall visual field. Warren et al. (1988) argue that while "the local expansions of objects and surface features contain heading information as well....... to test the sufficiency of the global aspects of the flow field however, local element expansion must be eliminated from test displays" (p. 650). Thus they used non-expanding dot texture elements in their simulation. Therefore these studies have not been concerned with the task of avoiding and achieving collisions with particular objects in the visual field, but with accuracy in perceiving heading while moving towards or across a relatively featureless planar surface.

One possible exception to this is a study by Riemersma (1981), who employed two visual arrays; a random-dot array and a roadway display, both represented as a plane which the observer appeared to be moving across. The roadway display consisted of edgelines and a segmented center-line, converging on the horizon, so that the simulation was of driving along a straight road. A signal detection procedure was employed whereby subjects received 1- or 2.5-second glimpses of the scene ahead and were required to state (with level of confidence) whether or not their path of movement was deviating from straight-ahead in that exposure interval. Examples of the desired and deviant headings were provided prior to presentation of stimuli.

Threshold rotating speed (the rate of trajectory change) was lower for the roadway simulation than for the random dot simulation. It was found in the roadway simulation that, regardless of forward speed, subjects could detect rotating speeds of 6 to 9 min of arc/sec with 75% reliability. Cutting (1986), in referring to this study, suggested that this represented a heading discrimination accuracy level of 1 degree, but both Riemersma (1981) and Warren et al. (1988) (in reference to Riemersma's work) argue that what the experiment showed was that subjects had high sensitivity to change in heading but were "insensitive to fixed heading" (Warren et al., p.651).

Riemersma's work corresponds more closely to the question at hand than other studies because we can think of the simulated road as a part of the optic array which must be kept in the center of the optical flow field. It is a surface that the car is to be kept in contact with while the rear of another car is one to be avoided. The road may not be a "patch which specifies an opening", but the driver must keep it in the center of the flow field (or alternatively, the center of the car windscreeen) and keep the expansion of the discontinuities (specific to the road) symmetrical. Thus it is possible to draw something of an analogy between Riemersma's work and the current study. Both (as will be seen in later sections of this chapter and also in Chapter 5) involve target 'safe' trajectories and challenge subject to discriminate these from 'unsafe' ones.

1.15 Utility of the focus of expansion

Riemersma's work would seem to be the only study which closely relates to the question at hand. But other studies on heading perception are important because they have raised questions about the usefulness of the focus of expansion. As mentioned earlier, Cutting (1986) reviewed a number of studies on the ability of subjects to locate the 'point of impact' on a surface which they were 'approaching'. He concluded that our ability to locate the focus of expansion is poor, but acknowledges, as do Warren et al. (1988), that there is a difference between the optical focus of expansion (determined by the direction of the person's travel) and the retinal focus of expansion (determined by where the person is looking).

This distinction is important to the collision-avoidance scenario. If the driver is fixating on the point where his/her car is travelling, then both the retinal and the optical focus of expansion coincide. Therefore the car ahead which he or she is trying to avoid will be outside, or moving outside, both foci of expansion if the two vehicles are not on a collision course.

But if the driver is looking elsewhere, such as at the lead vehicle (given that it is not in fact in his/her path), then the retinal focus of expansion is displaced from the optical focus of expansion, which is, optically speaking, still in the same place. Can we still perceive trajectory from this retinal flow, even though the optical focus of expansion may be outside or in the periphery of the visual field? Cutting (1986) argued that we can, but that our ability to do so is not dependent on the focus of expansion, optical or retinal. He went on to "contend that the focus of expansion in the optic array is a fiction of a particular choice of coordinate system for the spherical projection surface" (p.162) and appears to suggest that previous authors have not departed enough from the original Gibsonian hypothesis.

However, Warren et al. (1988) argue that heading is specified by the global outflow pattern, not the local focus of expansion (which they rename the focus of radial ouflow). It is possible, they argue, to accurately perceive heading in locomotion from the global outflow, or the part of it represented at any time on the retina, even though the focus of expansion may not be discernable or within the visual field at the time. Even though they did not manipulate or involve "local expansions of objects and surface features containing heading information" (p. 650) in their own experiments, they acknowledge the usefulness of such information. Thus, while they argue that the 'local focus of outflow' hypothesis is incorrect, they contend that the 'global radial outflow' hypothesis is valid (p. 658).

So the optical focus of expansion need not be visible in order for us to perceive our heading relative to an object on the basis of retinal flow information which is determined by the location of that optical focus of expansion. We can regard the rear of a stopped or slowing car which we are attempting to pass by as a local object or set of features whose pattern of expansion gives information on our heading relative to that object. But, as mentioned earlier, only Riemersma's (1981) research seems to have relevance to the question currently at hand.

1.16 Alternative rear light configurations and relative trajectory discrimination

Even though there does not appear to have been any research directly concerned with the question of accuracy in discriminating between trajectories leading to a collision with a given object and those resulting in a near miss, the question can still be asked; would alternative rear light configurations such as a triangular array improve the ability of following drivers to discriminate between safe and unsafe, or 'hit' and 'miss' trajectories?

If we take the usual pair of rear lights as the norm, what effects would various alterations have? One might assume that a single light would offer the poorest information, but this might not be the case. Llewellyn (1971; cited by Warren et al., 1988) found that subjects could judge headings accurately if that heading was respective to a single reference point. Warren et al. (1988) refered to this as "target drift" information, but suggest that a frame of reference (such as the edge of a video screeen) is necessary for this to be effective. However, real-world driving environments often do provide such a frame of reference, such as the car windscreen. A single rear light might therefore be very effective in terms of "target drift" information; if it drifts to the left in the visual field, then the driver must be going to pass it on the right. There is however a problem of a non-optical nature. A single taillight would have to be placed in the center of the rear of the car to help the following driver when swerving either to the left or to the right of that car. Placed in the center of the car's rear end, it would only assist the overtaking driver in avoiding the light itself and unfortunately not the outer edges of the car. Thus the single light might actually only be useful for motorcycles and parked vehicles (where the light is fixed to the roadward side) but not cars on the move.

The other option is to increase the number of lights and/or add a vertical component to the array (by making a triangle or a square). How could this aid the following driver? A triangular array would more clearly specify the symmetry or amount of asymmetry in the expansion of the set of lights as it is approached by the observer. The pair of lights shown in Figure 3 subtends only one visual angle. As the following driver closes in, this visual angle will change differently if the following driver is on a non-collision course (as on the right in Figure 3) than it would if he/she were on a collision course (as on the left in Figure 3).

This is because when the light display is not being directly approached, the light furtherest from the observer moves away (optically) from the center of the outflow faster than the nearer light does (aasuming that the eye is fixating on the point toward which the observer is heading). This produces a noticable shear in the light configuration. If the lights are being directly approached, however, the two lights move away from the center of the outflow with equal velocity. Furthermore, the two lights differ slightly in apparent elevation, with the nearer light being slightly lower, if they are not directly approaching (or being approached).

This information is usually adequate but perhaps it could be improved by adding a third light to make a triangle. There would now be three visual angles subtended, as can be seen from Figure 4, instead of just one. If the observer is approaching these lights directly (as on the left in Figure 4), the three visual angles will all change at the same rate as the lights move away from the center of outflow at the same velocity.

However, if the observer approaches them on a non-collision course (as on the right in Figure 4), not only will the three visual angles change at a different rate than they would for a collision course, but they will also change differently to each other. The semi-vertical visual angle closest to the observer will change more slowly than the furtherest one, such that the triangle will become sheared. A triangle is a more rigid structure than a pair of points, and so the symmetry/asymmetry in the expansion of the discontinuities should be more readily perceived. Thus the triangular array affords all the information that a pair of lights would, but it provides a good amount of additional information as well.

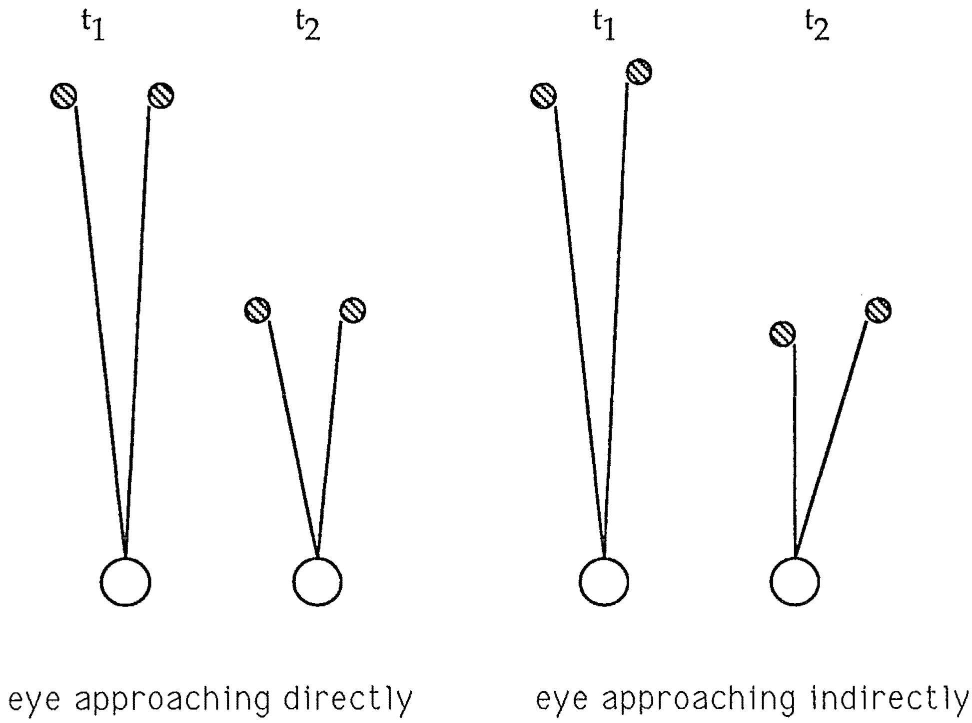


Figure 3: Changing visual angles as the eye approaches a pair of taillights directly or indirectly.

One might expect a row of three lights to be slightly better than a pair, since the nearer of the two subtended visual angles will increase at a slower rate than the further one if the lights are approached indirectly. However, such an array should not be as effective as a triangular one because it does not include a substantial vertical visual angle.

Thus we might expect that both a single light and a triangular array might be better than a pair of lights in allowing following drivers to discriminate between 'hit' and 'miss' relative trajectories. However, if this is the case, only the triangular array would actually be safer for collision-avoidance purposes, since the single light system would be misleading with regards to the actual dimensions of the lead vehicle itself.

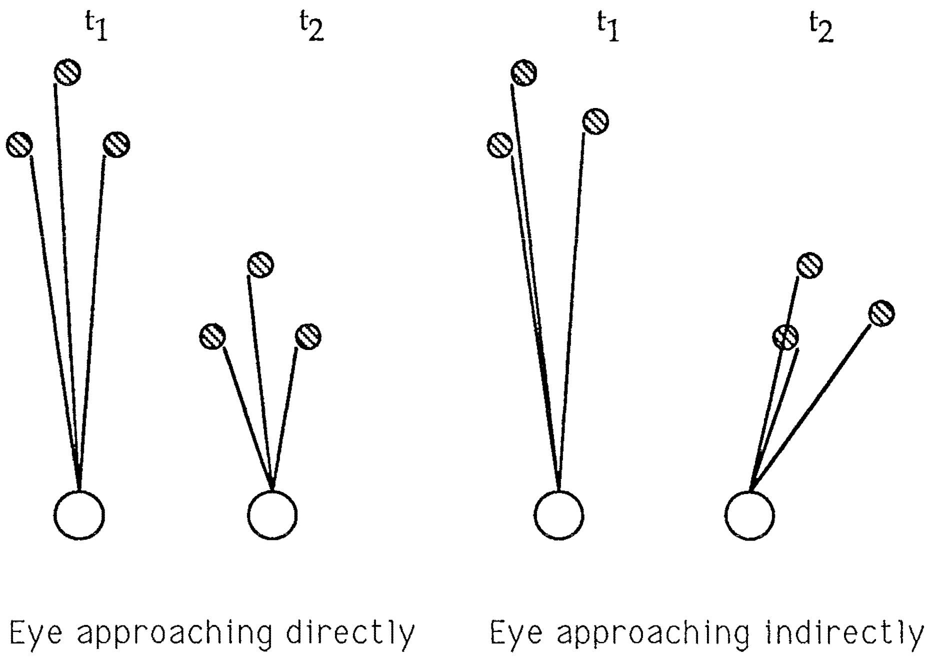


Figure 4: Changing visual angles as the triangle of lights is approached directly or indirectly.

However, this possiblity does not appear to have been examined by any researcher as yet. One study of possible relevance was however carried out some years ago by Micheals and Cozan (1963), who examined the effect of roadside objects on lateral displacement in driving. Subjects drove along an aircraft runway, having been told that their task was to maintain the vehicle at a speed of 15, 30, 45, or 60 mph. A reflectorised median strip was laid along the runway and, via photocells fitted to the underside of the car, a continuous recording of the car's lateral position could be made. At two roadside points along the way the 'displacing objects' were suspended from booms such that they were between 7 and 9.6 ft from the driver's (subject's) line of travel. The 'displacing objects' were in fact equilateral triangles (with a width of 6 ft) aligned sideways such that either the apex or the base of the triangle was nearest to the driver in any given trial.

Even though the 'displacing object' was never actually in the path of the driver, a trend similar to that later found by Triggs (1981) and Summala et al. (1981), in their analysis of driver responses to oncoming traffic, occurred. As the drivers approached and passed the triangles, they displaced their cars (laterally) away from them. The amount of displacement increased with increasing approach speed and decreased with increasing lateral distance between the triangle's location and the driver's line of travel. Lateral displacement began at a greater distance from the 'displacing object' when approach speed was higher and when lateral gap between the 'displacing object' and the driver's line of travel was smaller. But displacement was less when the apex rather than the base of the triangle was nearest the driver's line of travel.

Micheals and Cozan argue that there are two possible "visual mechanisms" through which a driver might be determining whether or not an object is in his/her path. One is the following trigonometric "rule of thumb": If at a certain distance the angle of the object (i.e., the angular difference between the driver's line of travel and the visual straight line to that object) is smaller than a critical value, the driver will displace from the object. The second "mechanism" is the rate at which that angle changes as the driver closes on the object; in other words, the rate at which the object moves away from the focus of expansion. If this angular velocity is below a certain value, then the driver will displace away from the object. The authors argue that the above-described pattern of results favour the hypothesis of critical angular velocity .

However, what is of further interest to the current discussion is that the lateral displacements were smaller when the apex rather than the base of the triangle was nearest to the driver. Thus when the 'displacing object' subtended a substantial vertical visual angle at the end nearest the approaching driver's line of travel, the driver's displacement away from the object was greater than when no such vertical angle was subtended. Therefore the rate of change in the vertical visual angle (where available) was also responded to by the driver.

Unfortunately, what this meant was that when the vertical visual angular information was available, these drivers were in fact less sensitive to the true state of affairs, since they took even greater evasive action to avoid an object that was never in their path. We can turn this argument around, however, to argue that the drivers were adopting safer avoidance behaviours when vertical visual angular information was available; they were in effect, for that situation at least, driving in a less risky, more conservative manner.

If a triangle is better than a pair of lights, one might expect an equilateral triangle to be the best triangular array in terms of afffording relative trajectory information via the symmetry/asymmetry with which the array expands. But if this information stems from the rate of change of the visual angles subtended in the configuration of lights, and, as mentioned previously in this chapter, angular velocity/displacement thresholds are higher for vertically-aligned visual angles than for horizontally-aligned ones, then perhaps it would be better to have a 'steeper-than-equilateral' triangle, since these thresholds are lowered with increasing initial visual angle. But it is not only the light-to-light visual angles that change. When the triangle is being approached non-directly, the three internal angles change, and change differently to each other; for example, the base internal visual angle futherest from the observer decreases while the nearest one increases. Given that in an equilateral triangle the three internal angles are initially the same, shearing in an equilateral triangle should be more easily noticed than shearing in a steeper triangle. Also, if the third light is mounted too high, it may be difficult for drivers to detect it's lateral displacement relative to the lower two lights that occurs when the observer is on a non-collision course with the lights. There is also the problem, as mentioned previously in this chapter, that mounting the third light so highly may, in the case of brakelights, defeat the original purpose of auxiliary brakelights, which was to have a brake signal light in a place where it would be readily noticed.

1.17 The rationale for Experiment 4

The basic aim of this experiment, presented in Chapters 5 and 6 of this thesis, was to ascertain whether rear light configurations which include both a substantial horizontal and vertical visual angular component allowed subjects to more accurately discriminate between 'hit' and 'miss' relative trajectories of the vehicle carrying these lights.

Several predictions were made:

1. A triangle of lights would be bettter than a pair of lights in that it would enable subjects to make more sensitive/accurate discriminations between collision and non-collision trajectories of an object carrying these lights.

2. An equilateral triangle would be better than a steeper- or flatter-than-equilateral triangle in terms of subject performance in discriminating collision from non-collision course trajectories.

3. A row of three lights might be better than a pair but would not be as effective as a triangle.

4. A single light was expected to also be better than a pair or row of lights but not as good as a triangle.

The six configurations of red lights used in Experiments 1(a) through 2(b) were employed for this experiment. They were the single light, the pair, the row of three (acting again as a density/frequency control), and the three triangular configurations. Again the basic widest horizontal visual angle subtended was the same for all light configurations consisting of two or more lights.

In addition to the type of light configuration, the trajectory of the vehicle (carrying the red lights) relative to the observer was varied: It either came directly towards the observer or deviated from that course by some amount, but it always travelled in a straight line from the same point of origin. The subject's task was to state after each exposure whether or not the target vehicle had been on a collision course with them, i.e., would it have collided with them had it kept closing on them.

The aim of the experiment was to find, for each light configuration, the relative trajectory at which the subject responded with chance level (50%) consistency regarding whether or not the target vehicle was on a collision course. It was expected that this 'ambiguous' or 'threshold' relative trajectory would be smaller when the target vehicle was marked by a triangle of lights or a single light than when it was marked by a pair of lights or a row of three lights.

1.18 Defining features of experiment 4

1.18.1 Laboratory simulation with stationary subjects

The scenario to be simulated was one in which a driver is approaching the rear of the car in front which, having been travelling in the same direction, is slowing or has stopped. The point of interest concerns finding the smallest relative trajectory that subjects perceive as specifying a non-collision course (which is not neccessarily the smallest relative trajectory that would in fact result in a non-collision course). The relative trajectory , in real world terms, refers to the difference between the lead car's trajectory and folowing car's trajectory, if the lead car is still moving, or the difference between the following car's trajectory and that taken by the lead car prior to stopping, if the lead car has stopped.

In Experiment 4 such relative trajectories were simulated by having stationary observers view the target vehicle approaching them. It would either come directly towards them (zero relative trajectory simulated) or it would deviate from this course by some amount. If it deviated from that course by 1 degree then it simulated a relative trajectory of 1 degree in real-world car-following terms.

Such a simulation would not be valid if any optic flow information other than that produced by the 'taillights' of the target vehicle were available. Thus the subject viewed these lights in what was otherwise complete darkness.

1.18.2 Monocular viewing conditions.

As with Experiments 1(a) through 2(b), the simulation was of a scaled-down nature with real depth information being available. Thus monocular viewing by subjects was neccessary for the same reasons as in Experiments 1(a) through 2(b).

1.18.3 Limited exposure, forced-choice procedure, double-staircase method

In this experiment subjects were given short glimpses of the target vehicle while it was moving and were required to immediately afterwards state whether or not it had been on a collision course with them. This format provided the basis for the execution of the double staircase method of threshold determination as described by Cornsweet (1962).

1.18.4 Triangles but not squares

For the same reason as that given in Section 1.11.6, square/rectangular light configurations were not examined in this experiment.

1.18.5 Generalisability

The simulation was intended to represent two possible (but very similar) situations, both in darkness. One is where the following driver is passing a much slower vehicle and has only the taillights of that vehicle on which to base his/her judgements about whether his/her current trajectory deviates sufficiently from one that would result in a collision.

The other is the situation in which the lead car has braked and has slowed rapidly or stopped, so that the second driver is closing rapidly. Again, the only visual information available to the following driver is the set of red lights, this time the brakelights. Again the following driver is trying to pass by this vehicle and needs to know if his/her current trajectory is sufficient to avoid collision.

1.18 Chapter summary

This chapter began with two questions, which concerned the effect of alternative rear light configurations on the ability of the following driver to detect changes in headway and to discriminate between relative trajectories which would lead to collisions and those which would not.

Much of the information that the driver uses in these tasks takes the form of visual angular information, such that time-to-collision, relative velocity and displacement, and relative trajectory of movement are all specified to the observer through the visual angles subtended by and between the lights in the lead vehicle's rear light configuration, and the changes to those visual angles occurring when that vehicle moves relative to the observer.

Therefore it was proposed that a rear light configuration which presents superior visual angular information, by adding a substantial vertical visual angular component to the existing horizontal one, should be better in terms of specifying relative motion and types of relative motion to the following driver.

The following chapters will be concerned with a set of laboratory experiments that were conducted to test this proposal.

2.METHODS: Experiments 1(a)-2(b)

2.1 Overview

The general aim of experiments 1(a), 1(b), 2(a), and 2(b) was to provide a scaled-down simulation of the visual array available to a driver who is following another car in darkness. The simulation's purpose was to provide information on (a) the amount of change in intervehicle spacing that is required before this change can be detected by the driver, and (b) whether different light configurations increase or decrease the minimum detectable change in distance.

In all experiments, the simulation of "intervehicle spacing" and "change in intervehicle spacing" was produced by having the subject view a miniature vehicle (to which a set of "rear lights" were attached). The vehicle was stationary at the beginning of every trial but might begin to move at any time. The subject's task was to respond as soon as the onset of movement by this "lead vehicle" was detected. In real-world terms, the subject would be detecting the onset of relative velocity between their own and the lead vehicle. The analogy between the simulation and the real-world event is best described by Figure 5.

Throughout all four experiments the initial distance between the simulated "lead vehicle" and the subject, the direction of movement of the lead vehicle (i.e. toward or away from the subject), and the arrangement of "taillights" carried by the "leading vehicle" were varied. In total, 5 initial distances, 2 directions of change of distance, and 6 light configurations were used.

2.2 Development of the apparatus

2.2.1 Establishment of real-world dimensions to be scaled down

It was intended that the simulator would be composed of a darkened chamber (containing the miniature vehicle) which the subject could look into from the outside. Thus the apparatus differed from that used by Mortimer (1972), where the target vehicle was situated in an open room along with and in front of the subject. Inside the chamber, the miniature vehicle was mounted on rails such that it would travel directly toward or away from the subject once activated.

Before this could be done however, estimates of a number of real-world dimensions were required so that an accurate scale simulation could be produced. The required measures were;

1. The actual spacing between the centers of the two conventional tail/brakelights on cars, the elevation of the centers of these lights above ground, and the elevation above ground of an auxiliary or center-high mounted brake light in the different positions that such a light might be mounted.

2. The spacing between vehicles normally adopted by drivers on the road.

To serve the first purpose, a tape measure was employed on the rear ends of a sample of cars from a Christchurch used car dealership. The mean values obtained for spacing of tail/brakelights on these cars are shown in Table 1.

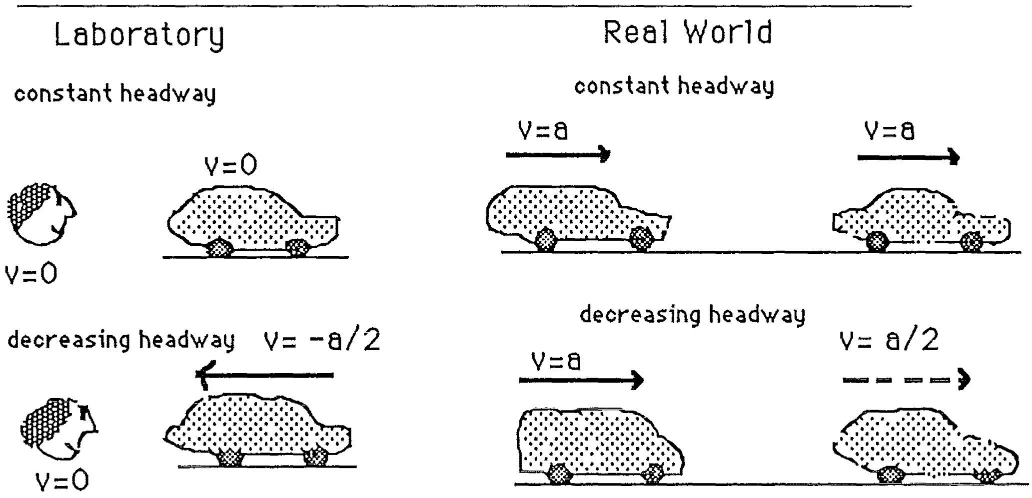


Figure 5: Analogy between the laboratory and the real world
(v= velocity)

Table 1: Mean values of spacing between rear lights and height of rear lights above ground for a sample of cars
(CHMBL= center-high mounted brakelight)

Horizontal distance between the centers of the two conventional tail/brakelights	1.30 m
Elevation of the centers of the conventional tail/brakelights above ground	0.70 m
Elevation of a CHMBL mounted in the bottom of the rear window	1.00 m
Elevation of a CHMBL mounted in the top of the rear window	1.30 m

The next step involved selecting a range of following distances that would reflect real-world conditions. At 50 km/hr a temporal headway of 1 second produces an intervehicle spacing of 13.89 meters, while a 4-second headway produces a 55.56 meter spacing.

Most countries recommend some safe headway for a given speed, defined either temporally or in terms of physical distance, but from the point of view of this study it was more important to base the simulation on the actual headways normally conceded by drivers, headways which are often considerably smaller than the recommended safe minimum.

2.2.2 What are the headways adopted by real-world drivers?

Lee (1971; cited by Rockwell, 1972, and Shinar,1978) used aerial photography to examine the temporal headways conceded by drivers on expressways. He found that in free-flowing traffic densities of 35 to 100 cars/mile, the minimum mean temporal headway was 2 seconds, and that this increased as traffic density increased. However, headways could be as short as 0.5 to 0.8 seconds when drivers were preparing to overtake. Harms (1968), using sensors placed on the road surface of a British motorway, found that, contrary to Lee's (1971) findings, the proportion of drivers following less than 1 second behind the vehicle in front increased as traffic density increased i.e. the average headway became shorter. Harms' study indicated that the proportion of drivers adopting a headway of less than 1 second varied between approximately 5% and 32%, depending on traffic density, weather and light conditions, time of day, and day of week. The average is not stated specifically but appears to be about 20%.

More recent Transport and Road Research Laboratory data (annual report, 1977) found similarly short headways. An analysis of traffic passing a close-following warning sign (of the automatically triggered variety) placed on the A332 road in Berkshire revealed that 39.2% of drivers were following at a headway of less than 1.6 seconds (with 23.2% less than 1 second) before the sign was introduced. Even after the sign was introduced (with the minimum headway that would activate the sign being varied) these percentages were 31.6% to 35.9% and 15.1% to17.6% for the 1.6-second (or less) and 1-second (or less) categories respectively.

Rockwell (1972a) suggests that drivers prefer a 4-second-plus headway in car-following, and will attempt to overtake if forced to adopt a shorter one. He adds however that in high-density traffic, "system restraints" (presumably prevention of overtaking) may force drivers to "operate below the National Safety Council Rule" (p. 145), which is quoted as 1.5 seconds. Some reconciliation of the Lee (1971) and Harms (1968) data is possible given Rockwell's distinction. It may be that Harms observed a traffic situation in which overtaking was not possible, or that he did not consider the possible role of overtaking actions (which are not mentioned in his report). Alternatively, Lee might have found results closer to those of Harms had he analysed a situation in which overtaking was restricted.

However some resolution this discrepancy is offered by Athol (1965), who looked at headways as they are affected by size of and position in 'platoons', which, in the terminology of traffic flow theory, refer to an identifiable, stable, and interacting set of vehicles. 'Platoons' are considered to be quite different to the more flexible 'group', where drivers are more independent of each other. Also considered was the degree of traffic congestion. Because Athol's definition of a platoon required temporal headways within the platoon of no more than 2.1 seconds, the headways of course were much smaller than those discussed by Rockwell (1972). Nevertheless 1.4 to 1.5 second headways were very common in platoons, while they were more in the 3.5 to 6.8 second range for 'groups'. This may explain the differences between the above studies; sizes of headways may differ depending on whether they are forced, elected, or coincidental.

Colbourn, Brown, and Copeman (1978) conducted an experiment in which drivers were to set for themselves the following distance behind a leading experimental car that they would normally adopt for various conditions. The subjects adopted a temporal headway of 2 seconds regardless of speed and other factors. However, it is possible that these subjects were driving in a manner that they thought would be desirable to the experimenters.

The above research suggests that drivers often adopt safe headways, but also suggests that they often adopt headways which are much shorter than the safe amounts.

2.2.3 Local field study

The above studies were done overseas and some years ago. In the interests of gaining some data of more local and contemporary relevance, a short field study was carried out over a single day at roadside sites in and around Christchurch. Four speed zones were considered;

1. A main street on which extensive roadworks to one side had considerably reduced the average speed of vehicles. This was defined as the 'slow urban zone'.

2. A similar street with uninhibited traffic flow, defined as the 'normal urban zone'.

3. A section of road with an open-road speed limit, one mile in length and connecting two urban areas. This was the 'fast urban zone'.

4. A section of State Highway, the 'fast rural zone'.

Measurement was obtained using a stopwatch; a crude method by the standards of the above research but nevertheless one which can still yield useful data. When a pair of cars passed, the stopwatch was started as the first car disoccluded a marker on the opposite side of the road. Timing was stopped as the second car occluded that mark. While some latency in watch activation would have occurred, it is most likely that latencies for stopping and starting the watch would be equivalent and would cancel each other out, thus yielding a relatively pure measure.

Traffic from both directions was included for analysis, as conditions for both were judged to be sufficiently similar. Pairs of cars or the leading two cars in a group were included for observation. Other types of vehicles were ignored. Pairs of cars passing the testing point which did not come into and depart from view as a pair were not included. Nor were pairs of cars showing an obvious speed difference or changing places in the traffic stream while in view.

All pairs of cars otherwise judged to be in a car-following situation were included. Judging whether such pairs of cars are in a follow-the-leader situation is a precarious affair, however, particularly in a single-observer roadside situation. It is quite possible that drivers conceding longer headways may have been judged as driving independently rather than in a manner influenced by the car ahead. Therefore the sample of data obtained may be biased toward shorter headways. This is acceptable, however, in that the minimum headways adopted by the drivers in normal conditions were of greater interest than the longer headways.

A total of 350 pairs of cars was included in the analysis. Means and standard deviations of headways for the four speed zones are shown in Table 2. An Analysis of Variance conducted for this data (using the SPSSX ONEWAY procedure) showed the main effect of speed zone to be significant ($F(3,346)= 3.188, p< .0239$), but a post-hoc Scheffe' test (SPSSX subcommand) indicates that this can be attributed to the difference between the fast urban and fast rural zones.

Table 2: Mean Temporal Headways (seconds) for the four speed zones

Zone	Sample size	Mean	S.D.	min.	max.
Slow urban	100	1.57	0.62	0.63	3.81
Normal urban	100	1.52	0.84	0.30	3.99
Fast Urban	100	1.34	0.70	0.24	3.14
Fast Rural	50	1.73	0.98	0.42	5.00
Total	350	1.51	0.77	0.24	5.00

Nevertheless the mean temporal headway overall was clearly less than 2 seconds and a considerable percentage of drivers followed less than 1 second behind the lead vehicle.

2.2.4. Headways and target sizes selected for simulation

On the basis of this data and the previous research it was decided that the apparatus to be constructed would simulate the visual array presented to a driver who is following another car at 50 km/hr where;

1. The temporal headway would range between 1 and 3 seconds, a range which seems to represent headways adopted by real-world drivers.

2. The dimensions of the configuration of rear lights on the lead vehicle corresponded to those listed in Table 1.

A scale factor of 1:25 was chosen as the largest scale that could be constructed and efficiently operated in the space available.

2.3 Description of Experimental Apparatus

2.3.1 Main Dimensions and Components

(Readers should note the set of photographs on the following pages, to be refered to in this section)

The target vehicle is situated inside a large box, the complete inside surface of which is painted with matt black paint. The box is constructed of wood (1.2 cm thickness) and the external dimensions of the box are 200 cm (length) by 30 cm (width) by 22.5 cm (depth). It is mounted on wooden legs of 20 cm length and the entire unit is placed on tables (Plate 1).

The top surface of this box consists for the most part of hinged lids which may be raised to reveal the experimental chamber (Plate 2). The subject sits at one end of the box and views the interior of it via a scope, which he/she looks through while a cloth hood (attached to the box) is placed over his/her head (Plate 3). A 24-cm high cardboard box is mounted atop the apparatus at the subject's end to prevent viewing into the chamber when the lids are open.

Inside the box is a 180 cm length of HO guage model railway track which runs down the center of the box. This track is mounted on a continuous strip of 5-mm thick foam rubber, which serves to reduce some of the noise and vibration produced by the target vehicle. The end point of the rails nearest to the subject is 8 cm from that end of the box.

Running parallel to the rails is a metal tape measure which is fastened to the floor of the chamber. The gap between the rails and the tape measure is 4 cm, and the tape measure is of the same length as the rails. The rails and tape measure are depicted in Plate 2, which also shows a birds-eye view of the target vehicle itself. A frontal-side view of this vehicle is shown in Plate 4.

A single speed was used for all experiments and conditions. This speed was calculated using stopwatch testing (Appendix 1) and is estimated to be 30 cm/sec, representing to the subject a simulation of a real-world relative velocity of 27 km/hr.

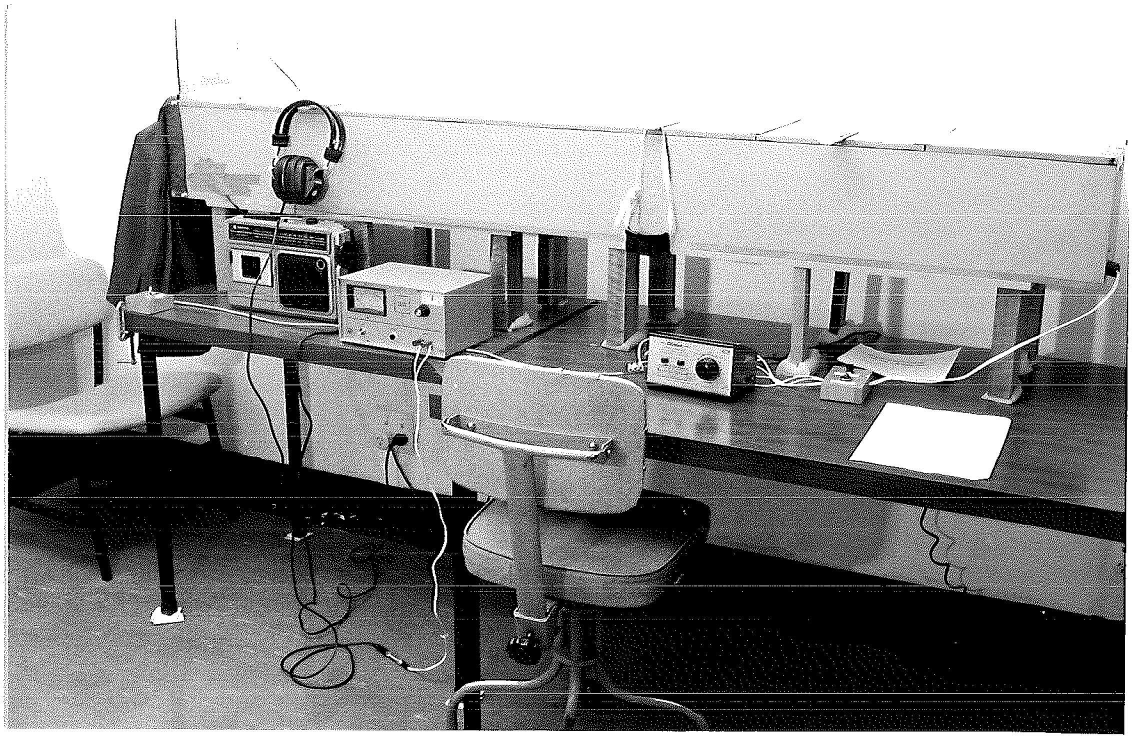
This target vehicle was intended to appear to the subject the same as the rear lights of a lead car would to a driver at night. The model locomotive and wagon are hidden from the subject's view by the light panel. As can be seen from Plates 2 and 4, the light panel and it's control/power box are mounted on a model wagon which is pushed/pulled by the model locomotive.

The only part of this vehicle which can be seen by the subject is the light panel, which consists of a metal plate (painted matt black) to which are attached six light-emitting diodes (LEDs). Attached to this plate is the control/power box, which features two switches; a power supply switch and a configuration selector switch with six settings. Power for the LEDs comes from a 1.5 V battery in the control/power box.

The six red LEDs are arranged in an upside-down 'T' as shown in Figure 6, which also shows the distances between the LEDs and their height above the floor of the box. Six different combinations of these lights can be activated by the configuration selector switch, and these six combinations are shown in Figure 7. Each combination

Plate 1 (Top): The Experimental apparatus (Experiments 1(a) - 2(b))

Plate 2 (Bottom): Interior of the apparatus (Experiments 1(a) - 2(b))



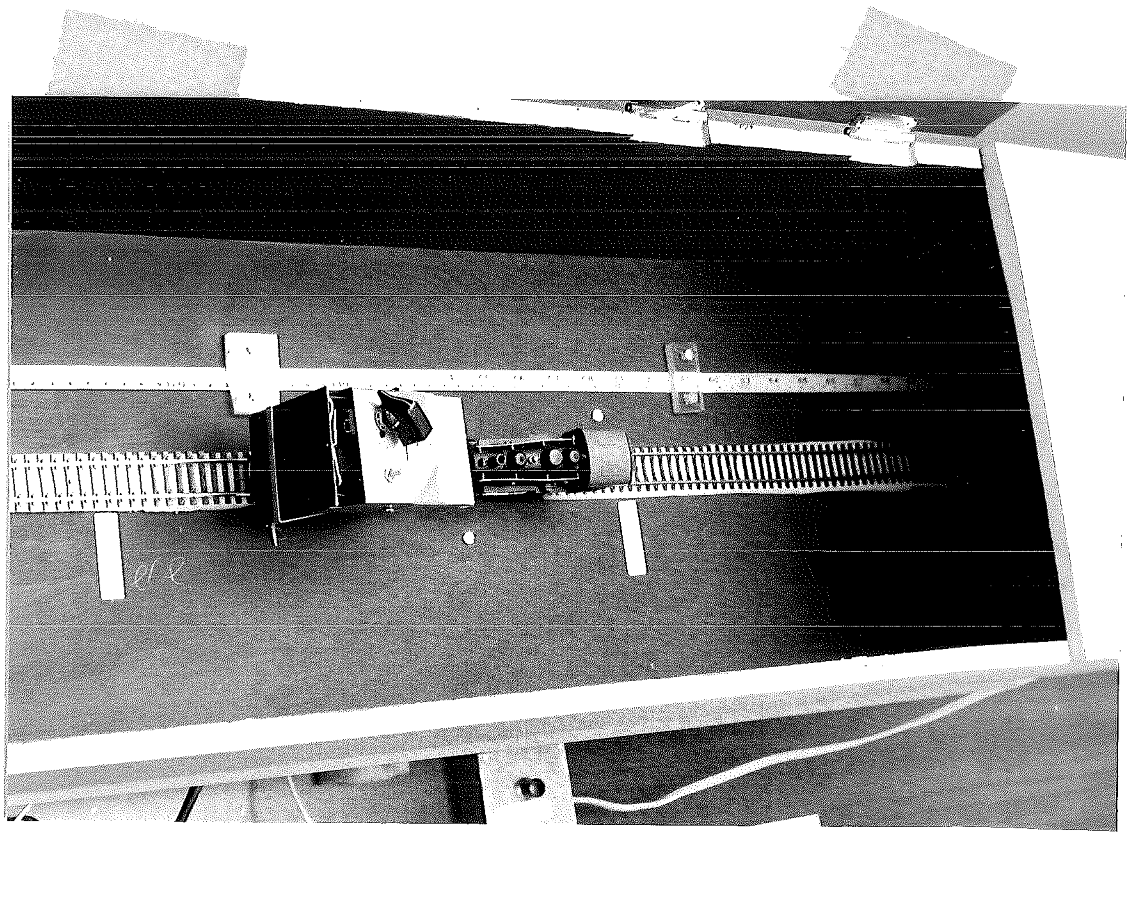
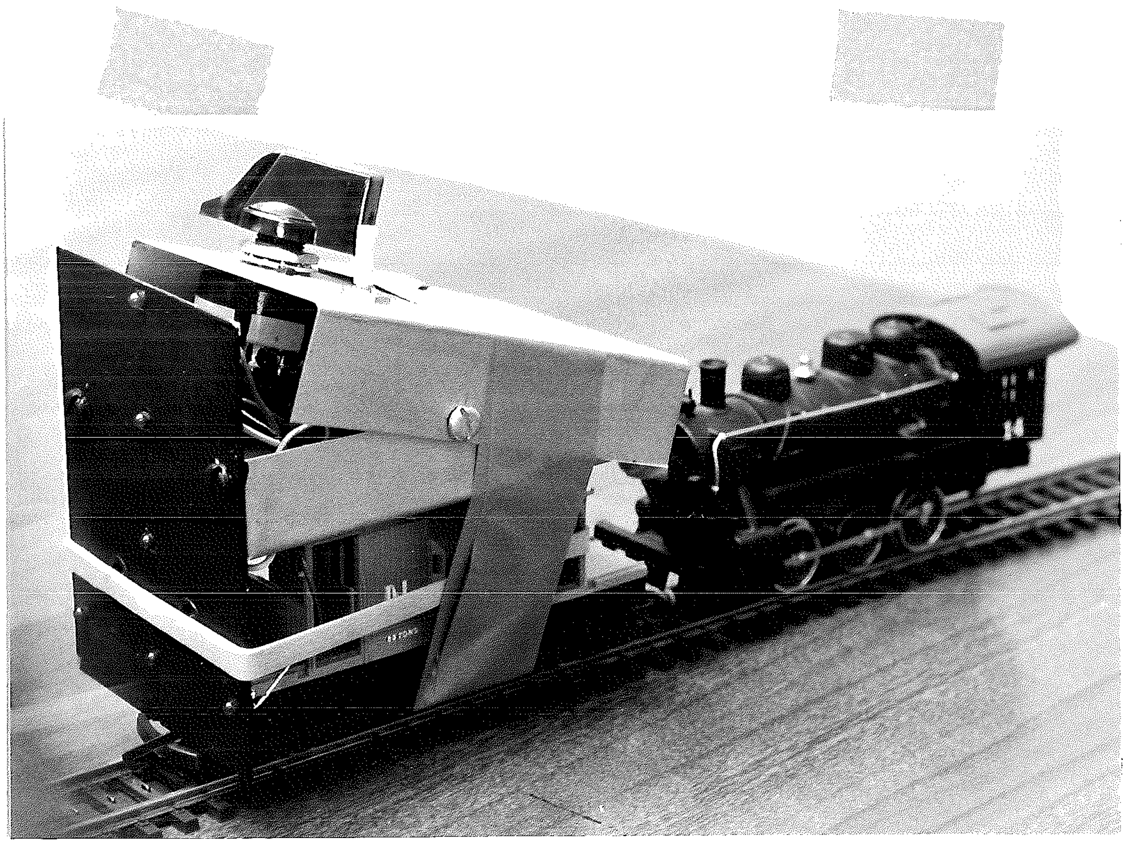


Plate 3 (Top): Subject positioned at the apparatus

Plate 4 (Bottom): The target vehicle



represents a particular real-world tail/brakelight configuration and it is neccessary to briefly describe them in these terms at this point.

Configuration A is the single light condition, representative of motorcycles and a handful of vintage/veteran cars still to be seen. The purpose of this display in these experiments is not to represent the motorcycle or the vintage/veteran car, however, but to act as a control for the effect of the changing size/brightness of an approaching or receding light. Note also that this light is in the geometric center of the equilateral triangle of lights in Configuration D. This was done so that a subject observing this single light would be focussing on the same point in space as would be the case when he/she was watching the equilateral triangle of lights.

Configuration B represents the standard 2-light taillight system carried on almost all cars.

Configuration C adds a third light between those of Configuration B. This configuration serves as a density/frequency control for configurations D through F i.e., it has the same number of lights, but does not have a vertical component in the configuration created by the lights.

Configuration D consists of an equilateral triangle of lights. Any pair

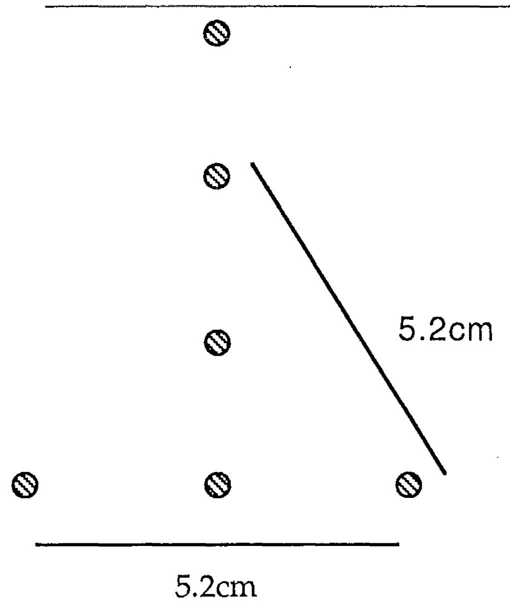


Figure 6: Arrangement of LEDs on the light configuration panel

of these lights thus subtends the same visual angle at the subject's eye. In the real world, this might correspond to a car which has two conventional tail/brakelights and an auxiliary center-high mounted brakelight in the top of the rear window, so that the display available to the subject is one that would be seen when the brakelights on this hypothetical car were activated. It also could be thought of as a continuously activated triangular taillight system similar to the one suggested by Mortimer (1972).

Configuration E is a variation of D. The 'high-mounted light' is in a lower position, corresponding to the bottom of a car rear window. The triangle of lights is compressed relative to D, and the diagonal visual angles subtended by the relevant pairs of lights are smaller than the horizontal one.

Configuration F is another variation on D, but here the third light is in a higher position, corresponding to an auxiliary center-high mounted brakelight mounted on the roof of a car. The triangle of lights is stretched relative to D, and the diagonal visual angles subtended by the relevant pairs of lights are larger than the horizontal one.

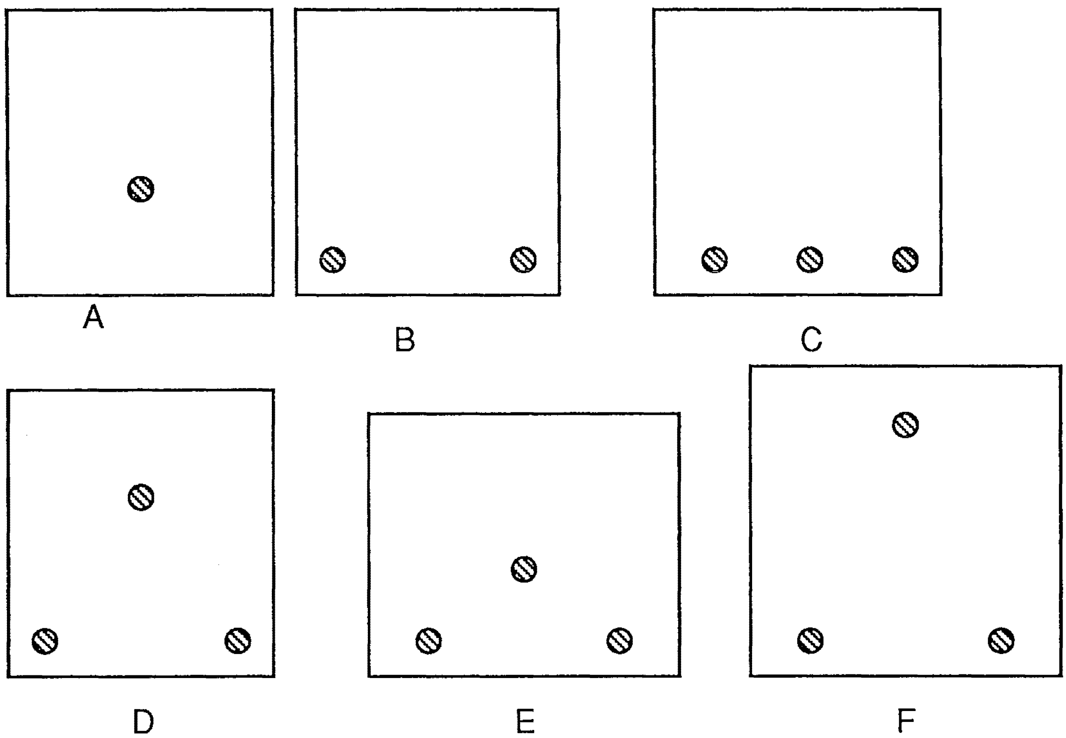


Figure 7: The six light configurations

2.3.2 Wiring and control for the main components

Figure 8 shows the wiring and control layout for the apparatus. The power supply for the model locomotive comes from a 12-volt DC model railway transformer, which also controls the locomotive's direction of travel. This transformer also produces the 16-volt AC output which lights the red indicator bulb.

The locomotive power supply circuit has two switches on it. One is the experimenter's starter switch, a non-locking push-on, silent switch which completes the circuit (setting the train in motion) while it is held down. The other is the subject's response switch, a locking, push-pull switch which controls two circuits; The locomotive power circuit (DC) and the indicator bulb circuit (AC). This switch, when pulled toward the subject, breaks the locomotive circuit and closes the indicator bulb circuit. The red indicator bulb thus signals to the experimenter that the subject has responded but has not yet returned his/her switch to the starting position for the next trial.

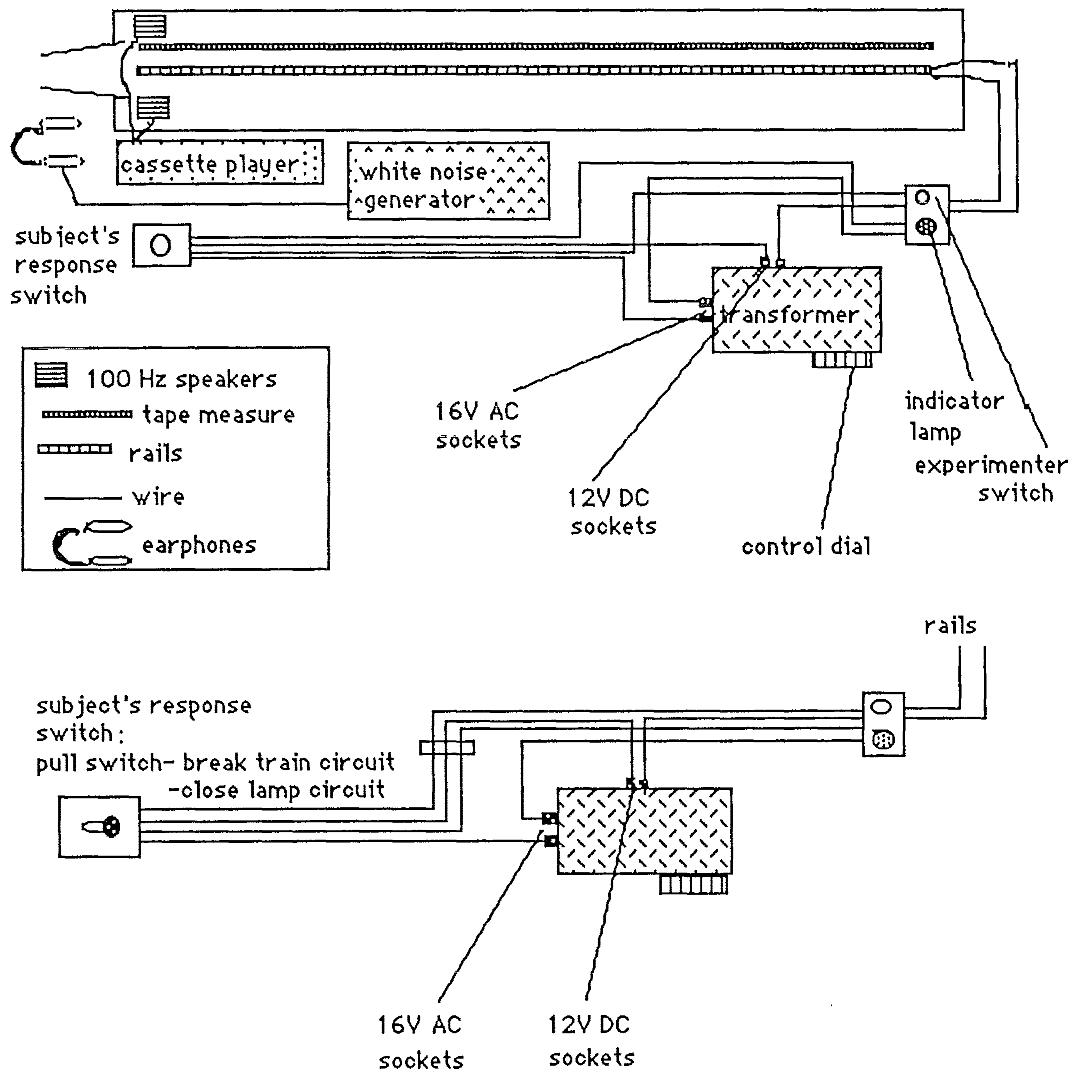


Figure 8: Apparatus wiring and main components

2.3.3 Auxiliary apparatus components

Two sound producing devices are included in the apparatus for the purpose of masking noise produced by the locomotive in motion. One of these is a Lafayette noise generator which supplies white noise through earphones worn by the subject. The loudness of this white noise is approximately 72 dB.

The other sound producing device is a Sanyo cassette player (5 W) which feeds a 100 Hz tone into Mini amplifier speakers placed inside the box at the subject's end. The estimated loudness of this is 73 dB at a point inside the box 10 cm from the speakers, or 64 dB at the location of the subject's head.

All subjects also wore Purafit foam rubber earplugs throughout the experiment as well as an eyepatch on their left eye (unless they were assigned to the binocular viewing group in Experiment 1(a)).

2.4 Subjects for Experiments 1(a)-2(b)

Subjects for these experiments were university students from various disciplines including psychology. Numbers (by sex) of subjects in each experiment were:

Experiment 1(a)	monocular viewing group	5 males	3 females
	binocular viewing group	3 males	1 female
Experiment 1(b)		3 males	5 females
Experiment 2(a)		1 male	7 females
Experiment 2(b)	normal distance	4 males	4 females
	control (near) distance	2 males	2 females

2.5 Subdivision of experiments

Although it is possible that Experiments 1(a) through 2(b) could have been combined into a single experiment, their separation was desirable for a number of reasons. One was that the procedure was a very tedious one for subjects to endure. About 30 trials seemed to be the upper limit of tolerance for subjects in the pilot testing sessions, and at least 96 trials would have been required to have combined all the desired conditions into one experiment. Therefore at least two seperate experiments were required. Thus it was decided to examine effects of initial distance in Experiment 1, and effects of direction of motion in Experiment 2. An initial distance different to those used in Experiment 1 was employed for Experiment 2 so as to provide an additional level of initial distance for analysis.

There were six different light configurations to be tested in these experiments, and this was too many to present in a single session. The light configurations can be divided into two overlapping groups. The first group, consisting of configurations A, B, C, and D, are the ones which were essential to examine the effects of number of lights, arrangement of lights (i.e., whether or not it contained a substantial vertical component), and size-brightness information. Thus four was the minimum stimulus set required to test the primary hypotheses. The second group, consisting of configurations C, E, D, and F, involves configurations which all feature three lights but vary in the size of the vertical component they contain, from no such component to a large one.

It was decided that it would be better to test these subgroups separately to minimise confounding effects (e.g., frequency effects, arising from the lower number of lights in configuration B, that might confound comparison of configurations C through F). Although there would be some overlap, the repetition was expected to increase the reliablity of the results obtained.

Therefore there were effectively four experiments on headway change detection carried out. Because they can be classified into pairs on the basis of common procedures, they are refered to as Experiments 1(a) and 1(b), and 2(a) and 2(b).

2.6 General Procedure for Experiments 1(a)-2(b)

Because there is much similarity in the procedures of Experiments 1(a), 1(b), 2(a), and 2(b), the procedural points which are the same for all experiments will be outlined in this section. The procedural aspects which are unique to particular experiments will be discussed in subsequent sections.

The Subject was seated at his/her position at the apparatus and was given a set of printed instructions which read as follows;

"Once you are in position you will find yourself looking into a darkened chamber. At some distance from you there is a stationary vehicle, which is marked by 1, 2, or 3 red lights. The vehicle may begin to move at any time, but is always stationary at the beginning of each trial. Your task is to detect any movement of this vehicle. Throughout the experiment, your right hand should be at the switch nearest to you. When you see the vehicle start to move, pull the switch **firmly** towards you (you can be as hard as you like on the switch; the main thing here is that the response isn't fumbled)."

"Activating this switch stops the vehicle and ends the trial. Once you have done this it is then neccessary for you to look away from the viewing scope. At this point the lid of the viewing chamber will be raised so that adjustments may be made for the next trial."

"The next trial begins when the chamber is closed again, at which time you may return your eyes to the viewing scope. When you are ready for the next trial return your switch to it's starting position."

"If you want a break at any stage let me know."

The subject was then asked if the instructions were understood. He or she was then fitted with the foam earplugs, eye-patch (over the left eye), and earphones. Each subject was given several practice trials before the blocks of test trials were administered.

A trial took the following form;

1. The subject indicated readiness by returning her/his switch to the position which closes the locomotive circuit and breaks the indicator lamp circuit.

2. The experimenter waited for a randomly predetermined interval (with a ceiling of 15 seconds) to pass before pressing the starter switch, which he continued to hold down. The locomotive would then start to move.

3. The subject would respond by pulling his/her switch. The locomotive would stop, and the indicator lamp would go on. The subject would then look away, at the experimenter.

4. The experimenter would then release the starter switch, open the chamber, note the point where the train had stopped (by refering to the tape measure), and shift the train to it's starting position for the next trial.

5. The subject would see the experimenter lower the chamber lid and would return his/her eyes to the viewing scope.

6. As for 1.

There was some variation among subjects on the minor points of the procedure. For example, some prefered to return the switch to the "ready" position a few seconds after responding and then wait for a wave from the experimenter indicating that they should look into the viewing scope again.

If on any occasion a subject responded before movement had actually occurred, the trial continued in accordance with the above format. Thus the subjects were not informed that they had made an anticipatory response. Subjects were warned prior to commencement of trials that this would be the case. Such erroneous responses were recorded, however, and the trial repeated later in the experiment.

At the end of the session the purpose of the experiment was explained to the subject.

Four pilot subjects were each put through a complete test session, three of them being tested on the procedure for Experiment 1(a), and the other one being tested on the procedure for Experiment 2(a). The data from these subjects was not used for further analysis, as these sessions uncovered a number of minor technical and procedural problems which were corrected before testing of other subjects began.

2.7 Procedure: Experiment 1(a)

Eight subjects were placed in the monocular viewing group (wearing an eye-patch over their right eye) and four were placed in the binocular viewing group (unrestricted vision). Light configurations A, B, C, and D were used in this experiment, and the target vehicle would commence movement toward the subject from one of three positions:

1. 56 cm from the subject's eyes
2. 111 cm from the subject's eyes
3. 167 cm from the subject's eyes

In the full-scale 50 km/hr driving situation, these distances would correspond to 1-, 2-, and 3-second temporal headways respectively.

With viewing state (monocular vs binocular) as a between-subjects factor, light configuration was imposed as a within-subject factor, with four levels, as was initial distance, with three levels. These factors were crossed, so subjects received 12 types of events. Each type was presented three times, producing a total of 36 trials (excluding practice trials).

The entire testing session was presented in four blocks, one for each light configuration. Each block comprised nine trials, such that each of the different initial distances was used on three occasions within a block. Initial distance was varied randomly within a block.

The order in which subjects received the blocks of trials varied between subjects in the manner of a Latin Square such that the order of blocks for Subject 1 was ABCD, while for Subjects 2, 3, and 4 it was DABC, CDAB, and BCDA. The three measures obtained for each combination of light configuration and initial distance were pooled so that 12 data points subsequently went forward for further analysis.

2.8 Procedure: Experiment 1(b)

The procedure for this experiment was more or less identical to that in Experiment 1(a) but the light configurations used for this experiment were C, D, E, and F (although the basic block order was CEDF, so that they were in order of increasing vertical component). Furthermore, all eight subjects in this experiment were monocularly tested.

2.9 Procedure: Experiment 2(a)

Eight subjects were monocularly tested for this experiment too. As for Experiment 1(a) there were four blocks of trials, for light configurations A, B, C, and D respectively, and the order of block presentation varied between subjects according to a latin square.

In this experiment however there was only one initial distance, a point 133 cm from the subject. From this point the target vehicle travelled either toward or away from the subject, the direction of travel being randomly alternated within trial blocks. These two within-subject factors, light configuration with four levels and direction with two levels, were crossed to produce eight stimulus types, with 3 trials for each. Thus there were 24 trials, in four blocks of 6. As with 1(a), the three scores for each of the eight combinations were averaged so that eight data points went forward for further analysis.

2.10 Procedure: Experiment 2(b)

The procedure for this experiment was more or less identical to that used in Experiment 2(a) except that the light configurations used were C, D, E, and F, with the basic block order being CEDF as in Experiment 1(b). Furthermore, while eight of the subjects in this experiment were presented with the target vehicle at the same distance as was the case for subjects in Experiment 2(a), another four were presented with the target vehicle at an initial distance of 74.3 cm from their eyes. All subjects were tested monocularly.

2.11 A Note on the Dependent Variable

In all of the experiments described, the measure of performance was the distance that the target vehicle travelled, derived from the point on the track where it stopped after the subject had responded (by cutting the power supply to the locomotive). The laws of momentum ensure that the target vehicle will have travelled for a short distance after the subject had responded. Laws of mass and acceleration ensure further that there will have been some period of acceleration at the beginning of each movement by the locomotive.

These facts of physics create two potential problems for the measure of performance used. One is that the distance of travel recorded is inherently longer than that required for the subject to detect the movement, although the excess distance is quite small. The other is the possibility that the subject had detected the movement during the target vehicle's acceleration phase, a possibility which would have implications for an experiment which relates to thresholds of relative velocity.

The first of these is made less problematic by the fact that the distance travelled by the train after the power was cut would be, up to a point (when full speed is reached), a constant fraction of the distance travelled before the power was cut. Beyond that point it would be a constant amount (because once the train has reached full speed it will have a constant momentum thereafter). This of course depends on whether the train has reached full speed before the subject responds.

Data provided in Appendix 1, which describes the speed and momentum testing carried out on the target vehicle, indicates that it would have attained full speed by the time subjects had responded. This deals with the second problem, but also simplifies the first because it means the post-response distance travelled by the target vehicle was a constant amount.

This meant that the data obtained could have been transformed by deducting this value. Unfortunately only an estimate of this value could be made using the procedures described in Appendix 1. It was therefore decided that data would be analysed as the actual distance travelled, with the estimated amount of post-response travel being used to make subsequent inferences about subjects' performance. For statistical purposes, it would make no difference whether the data was transformed in this way or not, so the raw data was chosen as the more reliable data to use primarily. The estimated distances required for acceleration and stopping and their relationship to the data obtained from the above experiments will be discussed more specifically in the next chapter.

3. RESULTS: Experiments 1(a)-2(b)

3.1 Errors in responding

The number of anticipatory responses was very small. In Experiment 1(a) there were 1.08 errors per subject, or 13 errors from a total of 445 trials. In Experiments 1(b), 2(a), and 2(b) respectively, there were 0.375, 1.0, and 0.67 errors per subject. Furthermore, there was no particular pattern in the errors. Hence they are not considered further in the analysis.

3.2 Results: Experiment 1(a)

A MANOVA (SPSSX 2.1) was executed with four levels of light configuration comprising one within-subject factor, three levels of initial distance comprising the second within-subject factor, and two levels of viewing state (monocular versus binocular) comprising the between-subjects factor. The dependent variable was the distance travelled by the target vehicle.

Table 3 shows the mean distance change broken down by light configuration, initial distance, and viewing state. These results are depicted in graphical form in Figure 9 (for the monocular viewing group) and Figure 10 (for the binocular viewing group).

The main effect of light configuration was significant ($F(3,30)=12.39$, $p< .001$), but this appears to be attributable to the much larger distance changes for Configuration A than for the other three light configurations, among which there seems to be no difference in subject response.

The main effect of type of viewing state was also significant ($F(1,10)= 6.1$, $p< .033$), with subjects who had binocular vision responding to smaller changes of distance than subjects who had monocular vision. Note also from Table 3 that the variance amongst subjects in the binocular vision group is much less than in the monocular vision group. The main effect of initial distance was also significant ($F(2,20)= 27.27$, $p< .001$), with distance change increasing with initial distance.

There was a significant interaction between vision condition and light configuration ($F(3,30)= 3.04$, $p< .044$). Looking at Figures 9 and 10, this interaction

Table 3: Mean and (standard deviation) of distance (mm) travelled by target vehicle, by light configuration, initial distance, and viewing state (Experiment 1(a)).

Distance	Configuration A	B	C	D	Vision
Near	128 (31)	105 (18)	107 (23)	117 (26)	monocular
	97 (15)	82 (11)	82 (5)	85 (12)	binocular
Medium	194 (52)	130 (28)	125 (34)	133 (48)	monocular
	123 (9)	90 (9)	102 (12)	86 (8)	binocular
Far	274 (113)	157 (39)	154 (37)	160 (48)	monocular
	145 (18)	114 (13)	126 (8)	111 (8)	binocular

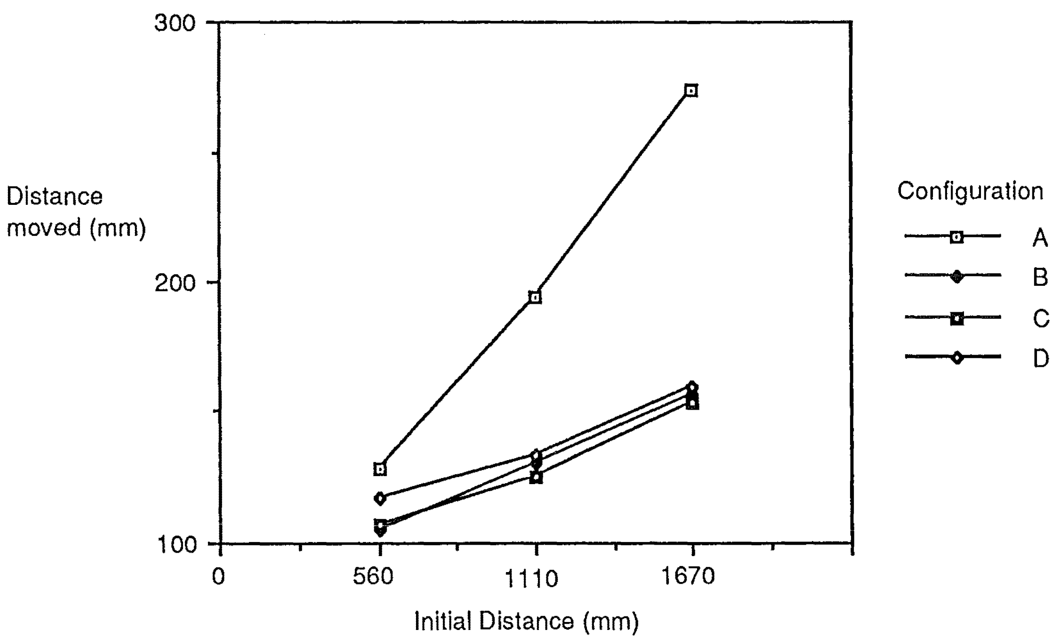


Figure 9: Distance change by light configuration and initial distance (Experiment 1(a), monocular group).

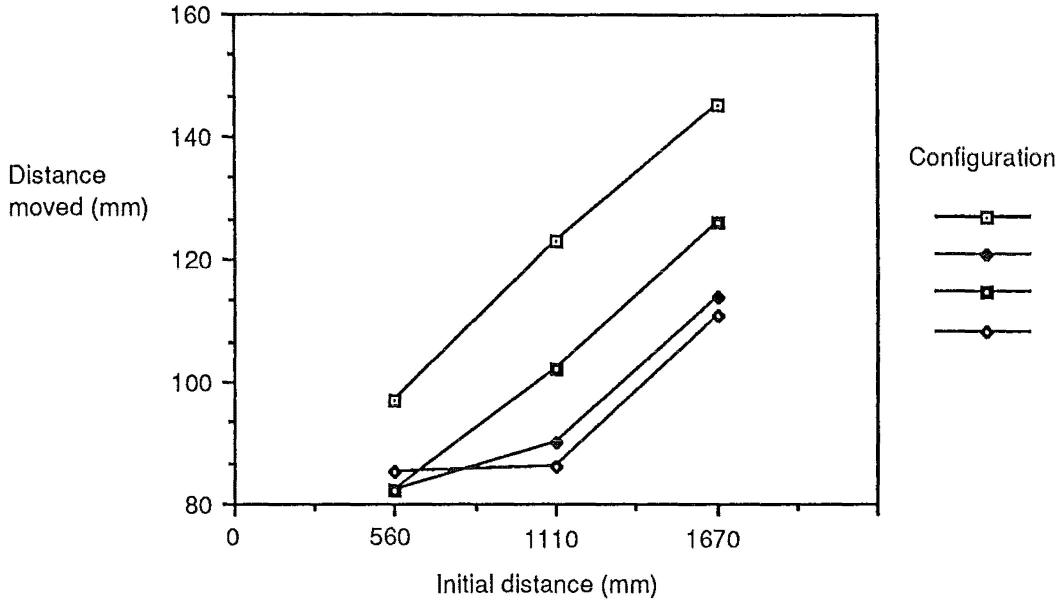


Figure 10: Distance change by light configuration and initial distance (Experiment 1(a), binocular group).

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appears to arise from the difference between Configuration C and the others which appears for the binocular vision group but not for the monocular vision group. The interaction between vision state and initial distance was not significant ($F(2,20)= 2.64$, $p<.1$) but the interaction between light configuration and initial distance was ($F(6,60)= 5.22$, $p< .01$). This interaction seems to be due to the trend visible in Figure 9 that, for the monocular vision group, the difference between Light configuration A and the others seems to occur at the medium and far distances but not the nearest distance. For the binocular vision group, however, this difference does seem to occur for all three initial distances. The three-way interaction was significant ($F(6,60)= 3.01$, $p< .012$).

A second MANOVA was executed, considering only the monocular vision group but now using the gender of the subject as a treatment variable (this was not feasible for the entire group, as only one subject in the binocular group was female). The results of the MANOVA are shown in Table 4 and in graphical form in Figure 9. There was no significant effect of gender of subject ($F(1,6)= .83$, $p< .396$). The main effects of light configuration ($F(3,18)= 14.27$, $p< .001$) and initial distance ($F(2,12)= 22.46$, $p< .001$) were again both significant, although the significance of light configuration is again attributable to the difference between Configuration A and the others. There was a significant interaction between light configuration and initial distance ($F(6,36)= 8.36$, $p< .001$), with the difference between Configuration A and the other configurations occurring at the medium and far initial distances but not the nearest initial distance. There was no significant interaction between sex and distance ($F(2,12)= .21$, $p< .814$) or sex and light configuration ($F(3,18)= .72$, $p< .550$). The three-way interaction was not significant ($F(6,36)= .566$, $p< .755$).

Table 4: Mean and (standard deviation) of distance (mm) travelled by target vehicle; by light configuration, initial distance, and sex of subject (Experiment 1(a), monocular group only).

	Configuration				
Distance	A	B	C	D	Sex
Near	118 (22)	100 (14)	108 (23)	105 (11)	male
	144 (41)	112 (24)	106 (28)	136 (35)	female
medium	186 (34)	119 (12)	119 (35)	120 (32)	male
	207 (83)	147 (43)	134 (36)	155 (70)	female
Far	250 (92)	149 (31)	155 (40)	145 (30)	male
	314 (154)	171 (52)	153 (39)	184 (71)	female

Light configurations B, C, and D had the same largest gap between any two lights, a gap of 5.2 cm. At the three initial distances of 56, 111, and 167 cm, the visual angles subtended are 5.3, 2.7, and 1.8 degrees, respectively.

The mean distance changes from each of the three distances for light configurations B through D combined were (considering the monocular group only) 110 mm, 129 mm, and 157 mm for the near, medium, and far distances respectively. After we deduct the distance travelled by the train after the subject had responded, a distance of approximately 3 cm (refer to Appendix 1 for the derivation of this value), we have the estimated minimum detectable distance changes of 80, 99, and 127 mm for the three initial distances respectively.

Table 5 shows the angular displacements that these changes of distance correspond to. It also shows the detectable distance change and detectable angular displacements as fractions of the original distances and visual angles. These fractions, in both the distance and visual angular forms, are the same for the medium and far distances but are noticably larger for the nearest initial distance.

Table 5: Minimum detectable distance change as a fraction of the original distance, and corresponding angular displacement as a fraction of initial visual angle (Experiment 1(a), monocular group only).

Initial distance	560mm	1110mm	1670mm
Change in distance	80mm	99mm	127mm
-percentage	14%	9%	8%
Initial angle	5.3^{o}	2.7^{o}	1.8^{o}
Change in angle	$.9^{o}$	$.2^{o}$	$.1^{o}$
-percentage	17%	7%	6%

3.3 Results: Experiment 1(b)

A MANOVA (SPSSX 2.1) was executed with four levels of light configuration as one within-subject factor, three levels of initial distance as the other within-subject factor, and gender as a between-subjects factor. The dependent variable was again the distance travelled by the target vehicle. Results are given in Table 6 and in graphical form in Figure 11.

The main effect of light configuration was not significant ($F(3,18)= .862$, $p< .479$), but the effect of initial distance was ($F(2,12)= 24.45$, $p< .001$). There was no difference between male and female subjects ($F(1,6)= .495$, $p< .508$). There was a significant interaction between light configuration and initial distance ($F(6,36)= 2.49$, $p< .040$). Refering to Figure 11, this appears to be due to the fact that Configuration E produced the poorest motion detection at the nearest and middle distances but the best motion detection at the furtherest distance. There was no interaction between subject gender and light configuration ($F(3,18)= .257$, $p< .855$) or between subject gender and initial distance ($F(2,12)= .372$, $p< .697$). There was no 3-way interaction ($F(6,36)= 1.03$, $p< .420$).

Configurations C, D, and E all had the same maximum subtendable visual angle, arising from the largest light separation of 5.2cm. However, Configuration F offered two larger separations of 7cm each. The mean distance changes recorded for each of the three distances were (for Configurations C through E) 110, 134, and 165mm for near, medium, and far initial distances respectively. For Configuration F these were 105, 122, and 159mm.

Table 6: Mean and (standard deviation) of distance(mm) change, by light configuration, initial distance, and sex of subject (Experiment 1(b)).

	Configuration				
Distance	C	E	D	F	Sex
Near	98 (5)	108 (23)	103 (10)	98 (6)	male
	108 (14)	123 (26)	112 (30)	108 (15)	female
medium	127 (41)	129 (41)	117 (18)	122 (22)	male
	128 (24)	153 (38)	137 (43)	122 (27)	female
Far	148 (33)	147 (41)	156 (31)	148 (33)	male
	178 (42)	157 (36)	187 (76)	166 (34)	female

We can deduct the estimated post-response travel of 3cm to get the estimated minimum detectable distance change values presented in Table 7, which also shows the corresponding initial visual angles and changes of visual angle.

Again, for both change in distance and change in visual angle, the fractions seem to be the same for the medium and far initial distance but are greater for the nearest initial distance. There does not appear to be a difference between Configuration F and the others.

Table 7: Minimum detectable distance change as a fraction of initial distance, and angular displacement as a fraction of initial visual angle (Experiment 1(b)).

	Configurations C-E			Configuration F		
Initial distance(mm)	560	1110	1670	560	1110	1670
Distance change	80	104	135	75	92	129
-percentage	14%	9%	8%	13%	8%	8%
Initial vis. angle	5.3^{o}	2.7^{o}	1.8^{o}	7.1^{o}	3.6^{o}	2.4^{o}
Change in angle	$.9^{o}$	$.3^{o}$	$.1^{o}$	1.1^{o}	$.3^{o}$	$.2^{o}$
-percentage	17%	10%	6%	16%	8%	8%

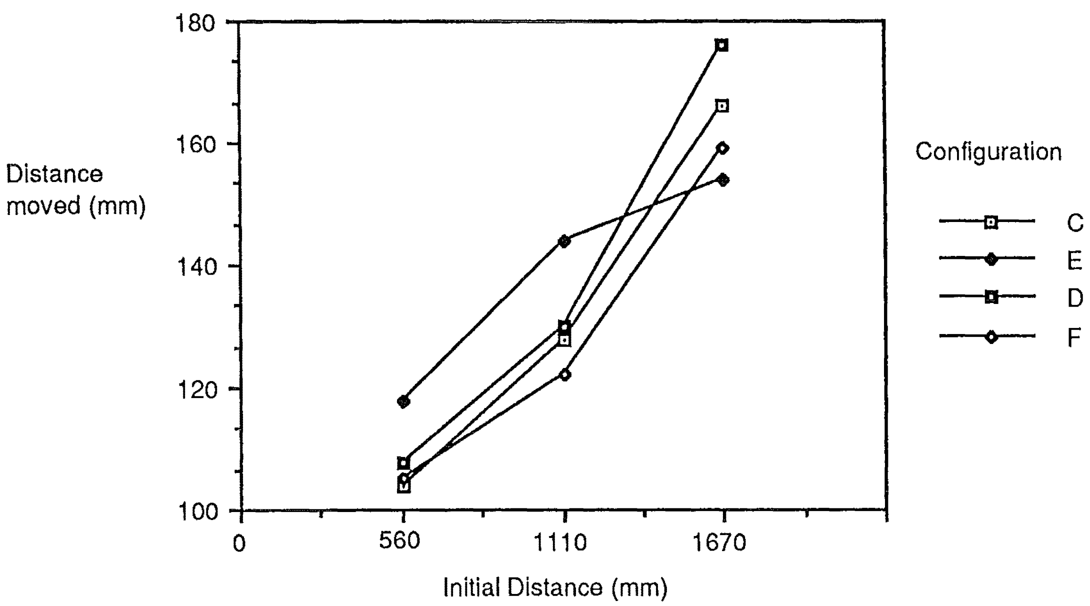


Figure 11: Distance change by light configuration and initial distance (Experiment 1(b)).

3.4 Results: Experiment 2(a)

A MANOVA (SPSSX 2.1) was performed on the data, with four levels of light configuration as one within-subject factor and two levels of direction of movement (toward or away from the subject) as the other. Gender was not considered as a factor since seven of the eight subjects were female and sex differences had not emerged in the previous experiments.

The data are presented in Table 8 and Figure 12. The main effect of light configuration was significant ($F(3,21)= 8.929$, $p< .001$), but, as for Experiment 1(a), this appears to be due to the great difference between Configuration A and the other light configurations. The main effect of direction was not significant ($F(1,7)= .247, p< .635$) and there was no significant interaction ($F(3,21)= 1.146, p<.354$).

Table 8: Mean and (standard deviation) of distance(mm) change, by light configuration and direction of movement (Experiment 2(a)).

	Configuration			
Direction	A	B	C	D
Toward	185 (77)	136 (46)	135 (49)	128 (29)
Away	181 (81)	130 (47)	133 (41)	151 (73)

The mean distance change for configurations B, C, and D was 133 mm for movement toward the subject and 138 mm for movement away from the subject. With all three configurations having the same maximum spacing of 5.2 cm, the visual angle subtended by these lights at the starting point, located 133 cm from the subject, is 2.2 degrees. Deducting the 3 cm post-response distance travelled by the target vehicle leaves mean distance changes of 103 mm and 108 mm respectively, for movement toward and away from the subject. Table 9 shows the distance changes and visual angle changes as fractions of their initial values for both 'toward' and 'away' travel. In terms of both distance and visual angular change as fractions of their original values, there appears to be no difference in minimum detectable distance change arising from the actual direction of travel of the target vehicle relative to the subject.

Table 9: Minimum detectable distance change as a fraction of initial distance, and angular displacement as a fraction of initial visual angle (Experiment 2(a)).

Direction of movement	Toward	Away
Initial distance	1330mm	1330mm
Change in distance	103mm	108mm
-percentage	8%	8%
Initial visual angle	2.2^{o}	2.2^{o}
Change in angle	$.2^{o}$	$-.2^{o}$
-percentage	9%	9%

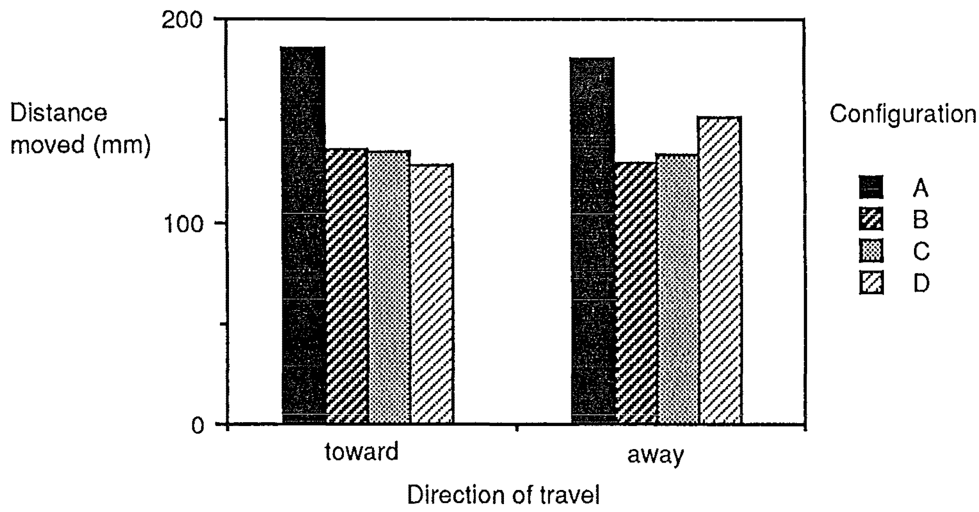


Figure 12: Distance change by light configuration and direction of travel. (Experiment 2(a)).

3.5 Results: Experiment 2(b)

The MANOVA for this experiment does analyse the effect of gender of subject, as the subjects are evenly distributed by gender in both the main and control groups. Initial Distance (normal versus control) served as the second between-subjects factor, with light configuration (four levels) and direction of travel (two levels) as the within-subject factors.

Summary data are presented in Table 10 and in Figures 13 to 16. The main effects of distance ($F(1,8)= 7.11$, $p< .029$) and gender ($F(1,8)= 5.858$, $p< .042$) were both statistically significant, with shorter distance changes for the nearer initial distance and males respectively. The main effects of light configuration ($F(3,24)= .586$, $p< .630$) and direction of travel ($F(1,8)= .00$, $p< .996$) were not significant. There were no significant interactions (appendix 2).

Table 11 shows the mean estimated changes in distance (i.e. with the 3 cm post-response travel deducted) as fractions of the initial distance, and the corresponding angular and angular displacement values. Configurations C-E are again combined separately to F. For all subjects, the distance travelled seems to be a constant (or approaching constant) fraction of the initial distance, regardless of the relative direction of travel. It must be remembered however that the visual angular values given in Tables 5, 7, 9, and 11 are derived only from the mean values of distance change. No variance values were obtained and consequently no parametric testing done. Therefore discussion on the visual angular data presented has minor weight and major limitations by comparison with the data on actual distance change.

Table 10: Mean and (standard deviation) of distance(mm) change, by light configuration, direction of travel, initial distance, and sex of subject (Experiment 2(b)).

		Configuration C		Configuration E		Configuration D		Configuration F	
Sex		M	F	M	F	M	F	M	F
TOWARD	Normal	117 (33)	160 (18)	134 (35)	186 (36)	136 (28)	166 (34)	118 (33)	143 (30)
TOWARD	Control	93 (23)	117 (18)	92 (16)	143 (13)	87 (1)	125 (9)	81 (3)	123 (0)
AWAY	Normal	138 (62)	176 (30)	128 (23)	162 (44)	130 (31)	168 (55)	121 (38)	161 (46)
AWAY	Control	90 (2)	118 (1)	87 (8)	120 (21)	87 (8)	114 (5)	89 (3)	135 (25)

Table 11: Minimum detectable distance change as a fraction of original distance, and angular displacement as a fraction of original visual angle (Experiment 2(b)).

	Configurations C-E				Configuration F			
Initial dist. (mm)	743		1330		743		1330	
direction	toward	away	toward	away	toward	away	toward	away
dist. change	80	73	120	121	72	82	101	111
-percent.	11%	10%	9%	9%	10%	11%	8%	8%
Initial vis. ang.	4^{o}	4^{o}	2.2^{o}	2.2^{o}	5.4^{o}	5.4^{o}	3^{o}	3^{o}
Change in vis. ang.	$.5^{o}$	$-.4^{o}$	$.2^{o}$	$-.2^{o}$	$.6^{o}$	$-.6^{o}$	$.2^{o}$	$-.2^{o}$
-percent	13%	10%	9%	9%	11%	11%	7%	7%

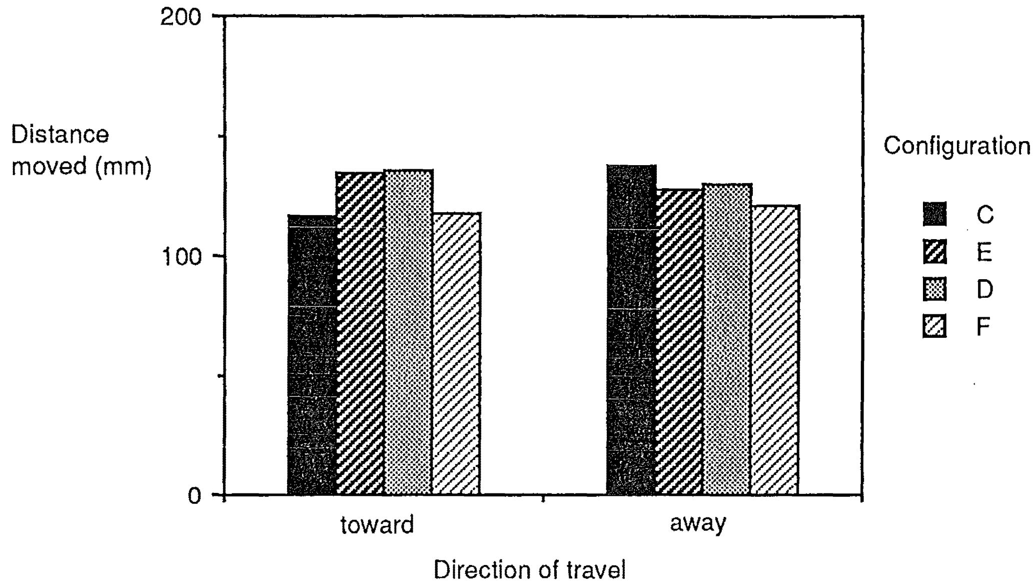


Figure 13: Distance change by light configuration and direction of travel (Experiment 2(b), male subjects at normal distance)

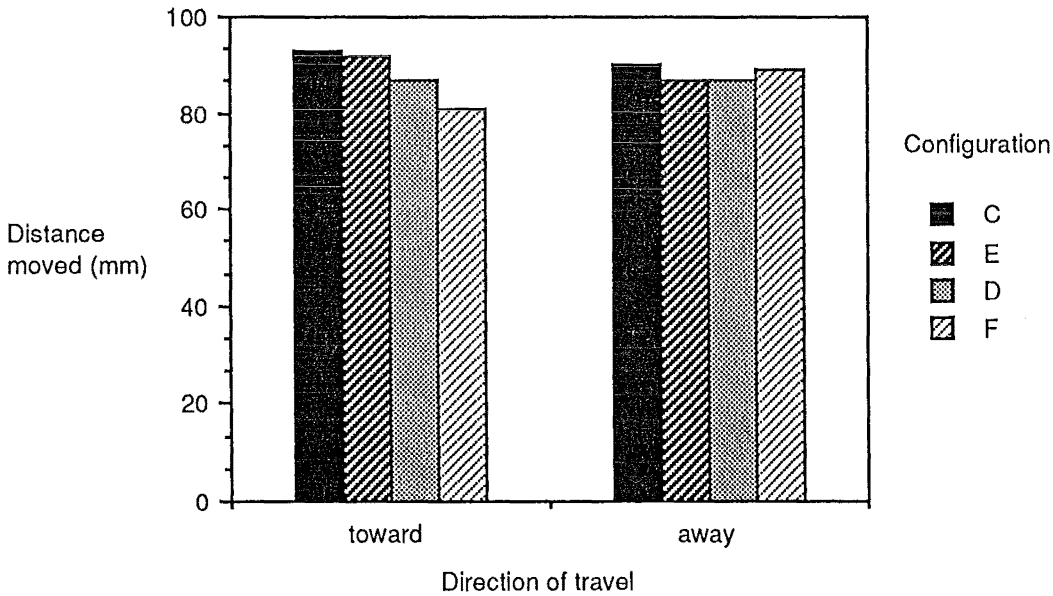


Figure 14: Distance change by light configuration and direction of travel. (Experiment 2(b), male subjects at control distance)

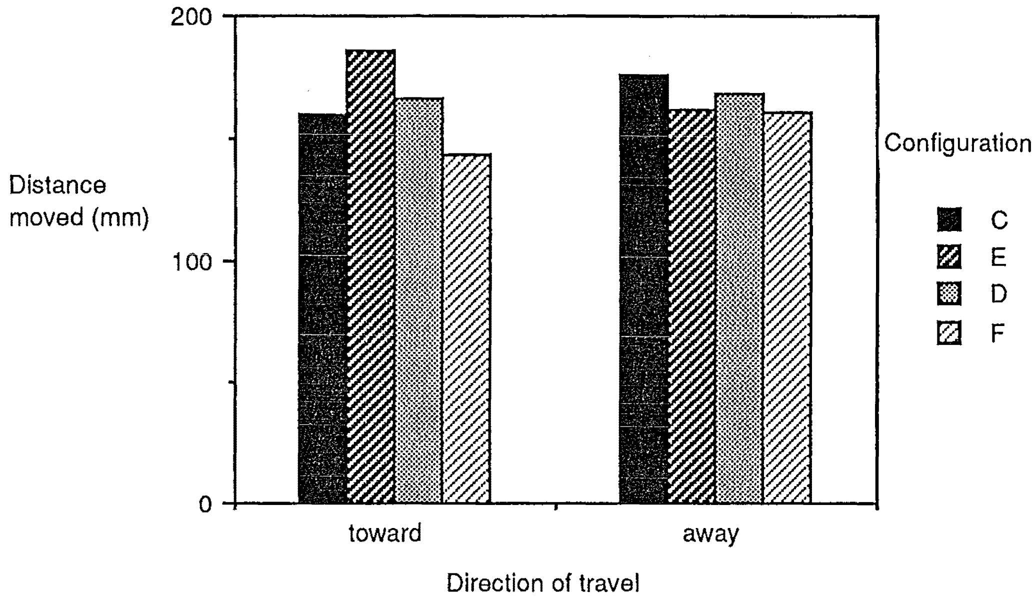


Figure 15: Distance change by light configuration and direction of travel. (Experiment 2(b), female subjects at normal distance.)

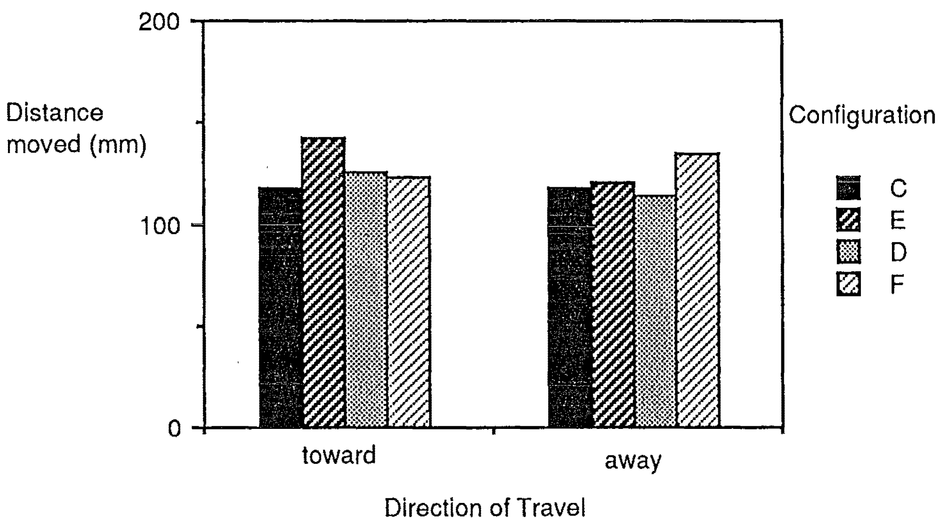


Figure 16: Distance change by light configuration and direction of travel (Experiment 2(b), female subjects at control distance)

3.6 Did motion detection occur while the target vehicle was still accelerating?

The smallest mean minimum detectable distance change recorded in experiments 1(a)-2(b) was 81 mm. If we deduct the estimated 3 cm post-response distance (appendix 1) then this is about 51 mm. In this case the train was running forward, and the estimated distance required to reach full speed is about 6 cm (appendix 1). It is possible then that in some cases the train was still accelerating when motion was detected, but the acceleration trends described in Appendix 1 suggest that it would have reached top speed by this point.

Most of the mean values of distance change obtained were, after the post-response travel estimate is deducted, above the 5 to 7 cm area of acceleration proposed in Appendix 1. It does not seem problematic that on a small proportion of occasions motion was detected within the latter part of the target vehicle's acceleration phase. The variable of interest is how much change in distance there was before the subject detected it, although the speed at which this was detected would of course be of interest in the wider theoretical sphere.

3.7 Discussion

In experiments 1(a) and 2(a) the distance change required for detection of movement in the case of the single light condition (A) was significantly greater than that for the other 3 light configurations. This was expected, since this configuration presents only size/brightness information about movement to the subject, whereas all the others present a substantial visual angle(s) subtended by the two or more lights.

There was however no difference in minimum detectable distance change between the other three light configurations (B, C, and D) for the monocular vision group. Therefore an increase in density (three lights instead of two) or the addition of a vertical component (three lights in a triangle instead of in a row) did not make movement easier to detect.

In experiments 1(b) and 2(b) there was no difference overall between any of the four light configurations (C, D, E, and F) in minimum detectable distance change. One interesting finding in Experiment 1(b) was that Configuration E seemed to offer the best motion detection information at the far distance, but was the worst at the nearer distances. This may be because Configuration E offers the smallest vertical visual angle(s) of the 3 triangular arrays, which would make motion detection harder at the nearer distances if subjects were attending to the vertical (or semi-vertical) visual angles as well as the larger horizontal visual angle, but which might not matter at longer distances where the vertical visual angles subtended by all the triangles are quite small. The problem with this argument is that it does not explain why motion by Configuration C (the row of three lights) seems to have been easier to detect than motion by Configuration E at the nearer two distances.

In general, however, enlargement of initial vertical visual angle did not make the motion more easily detected, as might be expected. Nor, overall, did adding any degree of 'verticalness' to the light configuration make motion detection any easier.

As expected, subjects with binocular viewing were able to detect smaller changes in distance than those with monocular viewing. This indicates that binocular vision enabled more accurate perception of motion in depth.

It is interesting that only subjects with binocular viewing seemed to find motion harder to detect for Configuration A than for other configurations at the nearest initial distance. It appears from this that not having binocular cues available gave the monocular view subjects a relative advantage in perceiving motion by the single light from the nearest initial distance.

In experiments 2(a) and 2(b) the target vehicle moved either toward or away from the observer, but the direction of relative motion did not affect the detection of that motion.

In experiments 1(a) and 1(b) minimum detectable distance change did increase with increasing initial distance. Experiment 2(b) included a control level of distance, included in the interests of ascertaining whether differences in motion detection due to the direction of travel were restricted to particular initial distances. There was of course no effect of direction of travel, but minimum detectable change of distance was less for the nearer (control) initial distance, as would be expected on the basis of experiments 1(a) and 1(b).

There was no difference between male and female subjects in experiments 1(a) and 1(b), but an effect of gender was found in Experiment 2(b). This does not appear to be due to the new direction of movement introduced in this experiment, as the effect is not confined to movement away from the subject. The sex difference may have been due to characteristics of the particular group of subjects used in this experiment, or possibly task differences between this experiment and the others. The sex difference issue will be discussed more fully in Chapter 7.

3.8 Summary of Key Results: Experiments 1(a)-2(b)

Two or three lights were better than one for allowing an observer to perceive movement, but there was no evidence to suggest that three lights, either in a row or in a triangle, were better than a pair of lights. Therefore adding a vertical component to the light array did not make motion relative to the observer easier to detect. There was, however, some suggestion in Experiment 1(b) that there is an effect of the size of the vertical visual angle, where one exists, at certain distances.

Subjects viewing with binocular vision responded to significantly smaller changes of distance (amounts of movement).

The further away the target vehicle was initially, the greater the distance change required for detection of movement. While this appears to be a constant fraction of the initial distance at distances corresponding to 2- and 3-second headways, it seems to be a greater proportion at a simulated 1-second headway. A similar pattern follows, generally, if the initial distance and distance change values are expressed in visual angle terms.

There was no difference in change of distance required for detection of movement that was dependent on whether the target vehicle was going toward or away from the observer.

A Sex difference, with better performance by male subjects, was found in one experiment but not the others.

4. EXPERIMENT 3: Evaluation of noise information

4.1 Aim

In spite of foam rubber earplugs, white noise through earphones, a 100 Hz tone coming from speakers inside the box, and foam rubber under the rails and under the supporting legs of the apparatus, it was evident from pilot and experimental testing that some subjects could hear (or possibly feel vibrations produced by) the motion of the target vehicle. It is possible that other subjects might also have been using this information without necessarily being aware of it.

Therefore some test of the effectiveness of this information in permitting the detection of target vehicle motion was needed. The results of the main experiments would still be valid if the noise signal was shown to be inferior in signalling the onset of movement; in other words, if subjects responded more slowly when only noise information was available, then the visual stimulus must have been a more salient source of information (or the one that was attended to first).

4.2 Subjects

The subject group consisted of twelve adults; seven males and five females. They were all tertiary students, aged between 21 and 25.

4.3 Procedure

The subject's task was essentially the same as for Experiments 1(a) through 2(b), except that there were no lights at all showing on the target vehicle. The subject wore the same eyepatch, foam earplugs, and white-noise emitting earphones used in the previous experiments, and the speakers inside the box produced the same 100 Hz tone at the same level.

Subjects received 12 trials, of which the first 3 trials were practice. The remaining 9 were randomly selected from one of three conditions:

1. Movement toward the subject from the 'near' point (560 mm) used in Experiments 1(a) and 1(b).

2. Movement toward the subject from the 'normal distance' (1330 mm) used in

Experiments 2(a) and 2(b).

3. Movement away from the subject from the same starting point as in 2.

4.4 Results

4.4.1 Method of analysis

Two separate MANOVAs were executed using the SPSSX 2.1 statistical package. The first had one within-subject factor (initial distance) and one between-subjects factor (subject gender). Thus it compared the results for the two conditions involving movement toward the subject. The second one also had one within-subject factor (direction of target vehicle movement) and one between-subjects factor (sex of subject). Thus the results for the two conditions where the target vehicle started from the 1330 mm distance were compared in this case.

The dependent measure was the same as for Experiments 1(a) through 2(b), i.e., the distance travelled by the target vehicle when the subject detected the movement (as before, this includes the post-response distance travelled by the target vehicle).

4.4.2 Initial distance and gender of subject

The means and standard deviations of distances travelled by the target vehicle are shown broken down by gender and initial distance in Table 12.

The main effect of distance was significant ($F(1,10)= 15.34$, $p<. 003$), but the main effect of gender was not ($F(1,10)= .757$, $p< .405$). There was no significant interaction between the two variables ($F(1,10)= .717$, $p< .417$).

4.4.2 Direction of movement and gender of subject

The means and standard deviations of distances travelled by the target vehicle are shown broken down by sex and direction of movement in Table 13. The main effects of direction ($F(1,10)= 1.61$, $p< .234$) and subject gender ($F(1,10)= 1.906$, $p< .197$) were not significant. There was no significant interaction ($F(1,10)= .151$, $p< .705$).

Table 12: Mean distance change (mm) by initial distance and gender of subject, for noise-only experiment (standard deviation in parentheses).

		Sex		
		Male	Female	Total
Distance	Near	171 (89)	207 (66)	185 (79)
	Far	215 (111)	274 (110)	239 (110)
	Total	193 (n.a.)	240 (n.a.)	

Table 13: Mean distance change (mm) by direction of travel and gender of subject (standard deviation in parentheses).

		Sex		
		Male	Female	Total
Direction	Toward	215 (111)	274 (110)	239 (110)
	Away	163 (79)	247 (116)	198 (101)
	Total	189 (n.a.)	260 (n.a.)	

4.5 Comparison of experimental results

There was no significant difference between the responses of male and female subjects generally. There does not, therefore, appear to be a gender difference in the criterion of response or detection of the noise.

Subjects took no more or less time to respond to movement toward them than to movement away from them. Thus any subtle noise differences arising from the direction of movement of the target vehicle had no effect on performance. Subjects did, however, respond sooner when the target vehicle was initially positioned closer to the them. This is to be expected in terms of physical laws of sound energy, as more sound and tactical vibration will reach the ears from a nearer source, so that the sound received will be further above threshold level.

There are a number of parallels between these results and those obtained in earlier experiments where the visual information was available. There was no sex difference in this experiment, nor was there one in Experiments 1(a) and 1(b). There was no difference atributable to direction of movement of the target vehicle, nor was there one in Experiments 2(a) and 2(b). Minimum detectable distance change did increase with increasing initial distance, as it did with Experiments 1(a), 1(b), and 2(b).

It could be argued then that this sound information alone might account for the differences in response due to initial distance of the target vehicle found in the other experiments. Furthermore, one might argue that the noise signal may have been the primary source of information in all experiments.

One way of examining these possibilities is to compare the results obtained here with those obtained for the equivalent distances and directions of movement in experiments 1(a)-2(b). Light configuration A resulted in the largest distance changes in those experiments. Table 14 shows the means and standard deviations of the distance changes for the 3 conditions of the noise-only experiment and the corresponding conditions for Light Configuration A in experiments 1(a) and 2(a). Three t-tests were carried out, comparing the mean for each noise-only condition to the mean for each corresponding condition where Light Configuration A could be seen.

The mean distance change for movement toward the subject from the nearer position is significantly greater in the noise-only condition than in the condition where Configuration A is visible ($t(18)= 2.25$, $p< .025$). However, for the far initial distance there was no difference between performance under noise-only conditions and that under conditions where Light Configuration A was visible, both in the case of movement toward ($T(18)= 1.29$, $p< .10$) and movement away from ($t(18)= .415$, $p< .10$) the subject.

This suggests that it is possible that subjects may have been using the noise signal to detect movement in the case of Experiments 1(a) and 2(a).

But subjects responded to significantly smaller amounts of movement when Configurations B, C, or D were available than when Configuration A was available, in Experiments 1(a) though 2(b). Is it possible that the subjects used the noise signal (knowingly or not) when confronted with light configuration A at larger distances, but used visual information when the better visual information was available, as with light configurations B-F? One way of ascertaining this would be to compare the mean distance change for the noise-only conditions to the mean distance change for the corresponding conditions where Light Configuration B was available. Table 15 shows this comparison.

Table 14: Mean distance change (mm) by initial distance and direction of travel for the noise experiment and configuration A from experiments 1(a) and 2(a) (standard deviation in parentheses).

Distance	Direction	Noise only	Configuration A (expt. 1(a),monocu- -lar viewing)	Configuration A (expt.2(a))
Near	Toward	185 (79)	128 (31)	— —
Far	Toward	239 (110)	— —	185 (77)
Far	Away	198 (101)	— —	181 (81)

Table 15: Mean distance change (mm) by initial distance and direction of travel for the noise experiment and configuration B from experiments 1(a) and 2(a) (standard deviation in parentheses).

Distance	Direction	Noise only	Configuration B (expt. 1(a),monocu- -lar viewing)	Configuration B (expt.2(a))
Near	Toward	185 (79)	105 (18)	— —
Far	Toward	239 (110)	— —	136 (46)
Far	Away	198 (101)	— —	130 (47)

In the case of movement toward the subject from the nearer starting position, subjects who could see Light Configuration B responded to significantly smaller amounts of distance change than subjects who had only noise information (t(18)=

3.38, $p < .001$). In the case of the farther initial distance, subjects having the visual information available did significantly better in detecting both the movement toward them ($t(18)= 2.89$, $p < .005$) and away from them ($t(18)= 2.027$, $p<.05$).

It appears from these comparisons that subjects were using the visual information rather than the noise information for the 2- and 3-light configurations in all situations, and for the single light configuration condition when the initial distance was small. However, when the single light was being viewed from greater distances, it is possible that subjects were using noise information.

4.6 Discussion and conclusions

The noise created by the target vehicle's movement was, despite the auditory 'buffers' put in place, perceivable by subjects, and it appears that they may have been using this information, knowingly or not, when faced with Configuration A at longer distances, in the previous experiments. It is unlikely that they were responding to auditory information when faced with other light configurations, or Configuration A at short distances, however, as they responded sooner than was the case when only noise was available.

The lack of a difference between performance in the noise only and single light conditions was only found when the target vehicle was at the farther initial distance. When it started moving from the nearer starting point, the changing size-brightness information seems to have been superior to the noise information.

It is worth noting that in no case was the sound information actually superior to visual information. It appears that it was inferior to angular velocity information (given by 2 or 3 lights) at all distances and changing size-brightness information at nearer distances. At farther distances it was equal to size-brightness information.

It seems doubtful that the subjects were using the sound information in experiments 1(a) through 2(b). Only a few subjects reported being able to reliably hear the noise of the target vehicle in those experiments, and others said they were not certain of the presence of noise until they had seen movement. Furthermore, the subject's attention was not drawn to possible noise information in the previous experiments, whereas in this experiment it was the only information available. The analogy of the apparently superior hearing abilities of blind people is pertinent here.

5. METHODS: Experiment 4

5.1 Overview

The purpose of this experiment was to examine the ability of subjects to discriminate between a trajectory that would lead to a collision and one that would not. More precisely, they were confronted with the target vehicle, again only visible through it's red marker lights, which was travelling in their general direction. After viewing it for a short interval, they were required to state whether the target vehicle would have hit the center of their right eye or passed to the right side of that eye. The true trajectory of the target vehicle's travel was of course varied.

In the simulation, the subject was stationary and the target vehicle moved toward her. This was intended to represent a real world situation in which the driver is closing on a slower moving or stopped vehicle from behind, and must decide whether or not his/her current trajectory would result in a collision if no change were made to it. As with experiments 1(a) through 2(b), absolute velocities and trajectories are used to simulate relative velocities and trajectories. This relationship is illustrated by Figure 17.

5.2 Description of Apparatus

The apparatus used in experiments 1(a) through 2(b) and Experiment 3 was substantially modified at the completion of those experiments. The white noise generator and headphones, the 100 Hz tone-producing speakers, and the foam earplugs were not required for this experiment and were withdrawn. The metal tape measure that had been fixed beside the rails inside the box was also removed. No subject's response switch was needed in this experiment, so the train control circuit was reduced to the power supply unit and the experimenter's switch, the non-locking, normally-off, push-button switch. The cardboard box that had previously been placed atop the apparatus at the subject's end was removed.

A stainless steel shutter, resembling a guillotine, was installed in the viewing chamber 11 cm from the subject's end. Normally closed, this could be raised by the experimenter, using a handle on it's top edge, to reveal the rest of the chamber to the subject. The purpose of this shutter was to ensure that the experimenter could completely and easily control the subject's viewing interval, which could not include time during which the target vehicle was stationary.

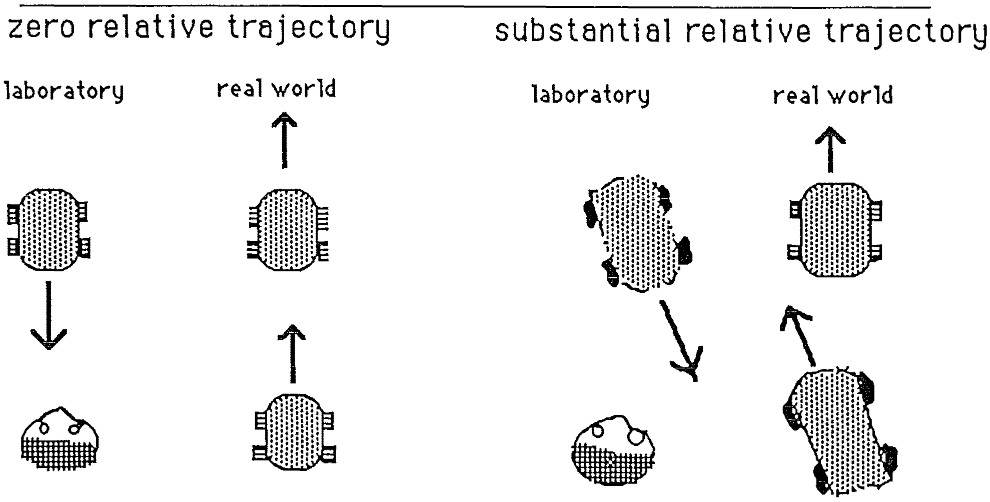


Figure 17: The analogy between the laboratory and the real world.

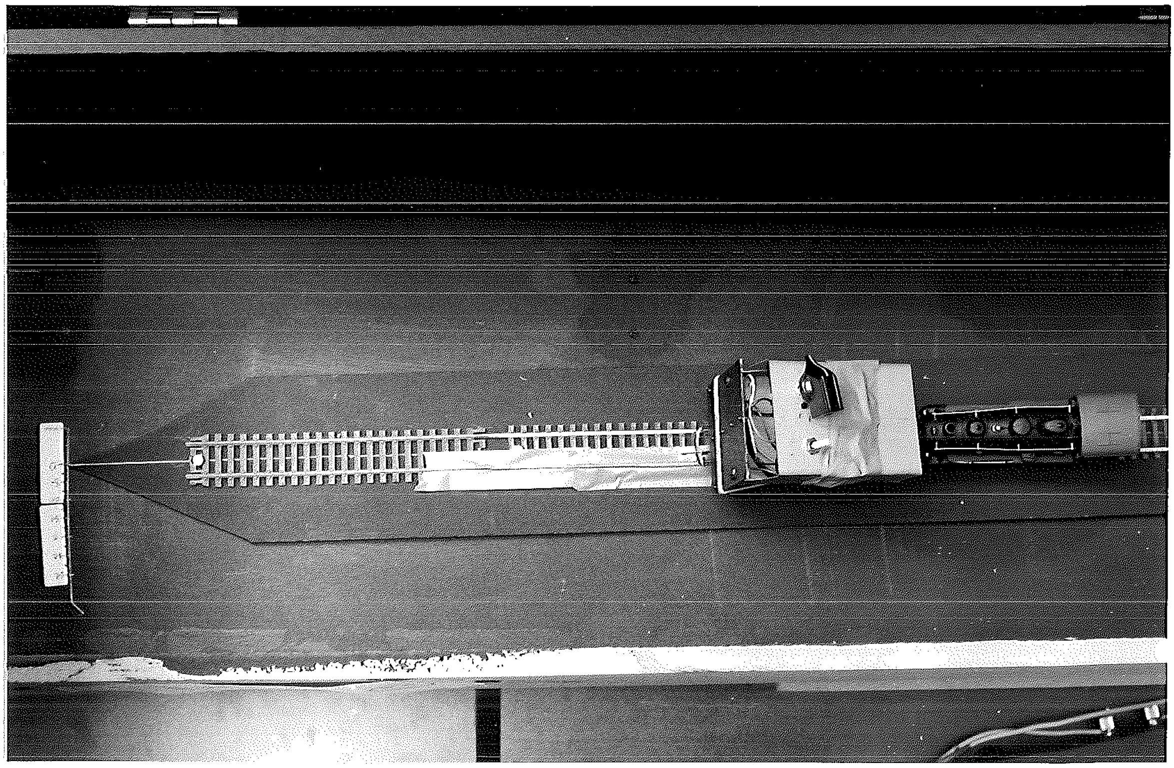
The rail length was reduced to 106 cm and the entire length was mounted on a strip of plywood which was painted matt black. This 9 cm wide, 115 cm long strip was positioned such that it ran down the center of the chamber. At the end furtherest from the subject, it was fixed to the base of the chamber by a metal axle, which entered the wooden base of the chamber 13 cm from that end of the box. At the end nearest the subject, the plywood strip was sharpened to a point, this point corresponding to the center of the rails. The plywood strip was thus in effect a swinging arm with the rails mounted on it. The axis of this swinging arm was at the end furtherest from the subject.

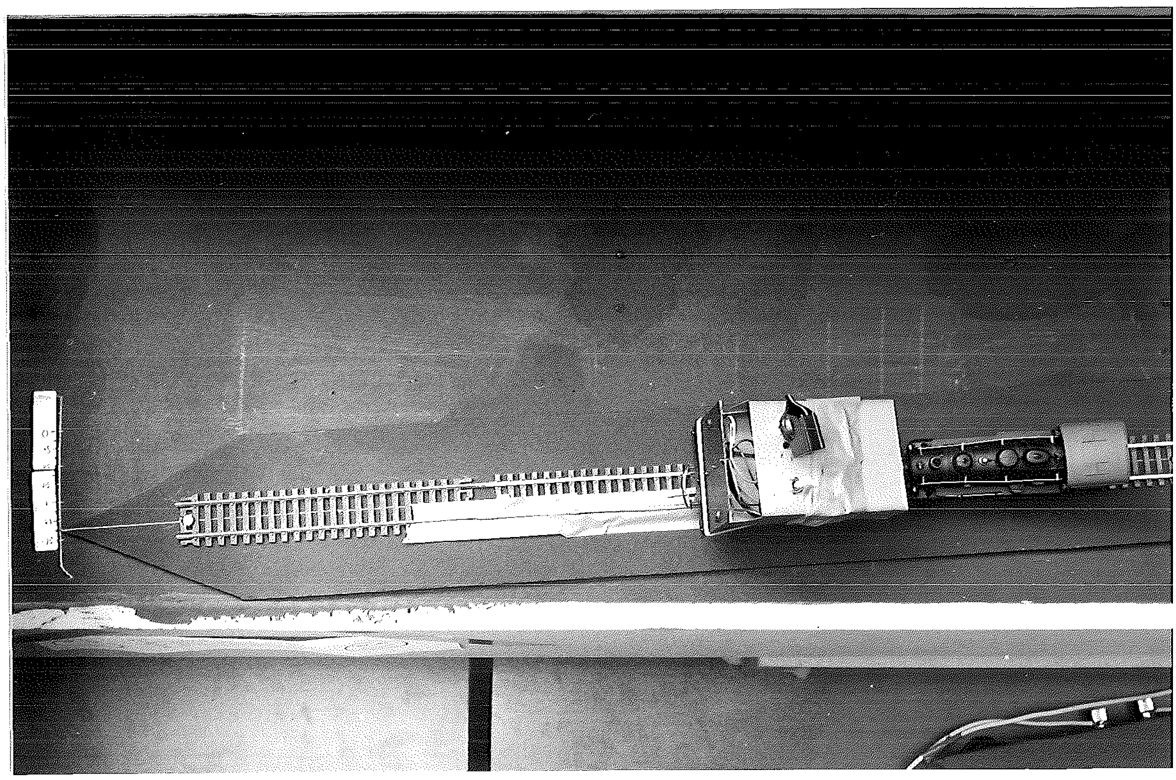
This swinging arm could be adjusted so that the target vehicle, when set in motion, would either travel straight toward the center of the subject's right eye (Plate 5) or would travel towards some point that lay to the right of the subject's right eye (Plate 6).

All trajectories used are described in terms of their amount of deviation, in degrees, from one which leads to the center of the subject's right eye. Thus the "straight ahead" or "hit" trajectory, the one which leads to the center of the subject's right eye, is refered to as having zero deviation. The true deviating trajectories ranged from 0.25 to 3.00 degrees, in increments of 0.25 degrees. Thus there were in all 13 possible trajectories which the subject might be confronted with, of which only

Plate 5 (Top): The apparatus set to produce movement on a zero relative trajectory

Plate 6 (Bottom): The apparatus set to produce movement on a substantial relative trajectory





one was truly a "hit" trajectory. The viewing scope used by the subject ensured that the center of her right eye was always in the same place.

At the end nearest to the subject, the railhead was 76.5 cm from the subject's end on the box. At this end of the rails, one rail was covered for a short part of it's length with plastic insulating tape. The tape served to break the current flowing to the model locomotive, thus stopping it when it reached this point.

Trials always involved the target vehicle running towards the subject from the furtherest end of the rails. The train always ran for about 2.5 seconds over a distance of approximately 80 cm.

5.3 Subjects

The four subjects were all female post-graduate students (non-psychology) of approximately 21 to 22 years of age. The procedure required the subjects to participate for a total of approximately 2 hours each, so all subjects were paid for their participation.

These subjects had been tested in experiments 1(a), 1(b), 2(a), or 2(b). They were asked to return for this experiment because they had performed better than average in the previous experiments and had been similar amongst themselves in terms of their performance on the previous experiments. Furthermore, they represented a uniform group in terms of age and gender. Therefore they were selected as a group amongst which there should be few individual differences that might confound the results of this experiment.

5.4 Procedure

The aim of the experiment was to find the trajectory(ies) which the subject judged to be the "hit" trajectory 50% of the time, as opposed to the trajectories which subjects judged with relative certainty to be either "hit" or "miss" trajectories. It was necessary to find this threshold region for each of the six different light configurations, and it was also important that each subject should be tested for all six configurations.

A signal detection theory procedure was not feasible because of the sheer number of trials needed to meet the above requirements. Many traditional methods of threshold estimation were unsuitable for the same reason.

However, the double-staircase method described by Cornsweet (1962) is particularly useful for this sort of situation, as it both avoids extensive presentation of stimuli which are well outside the threshold range and largely overcomes the problem of the single-staircase method, where subjects may easily work out the routine and produce fake but apparently consistent results (Cornsweet, 1962, McBurney and Collings, 1984). The double-staircase allows the tracking of the 50% threshold within a relatively short number of trials, and thus makes it possible for a single subject to be tested with a larger number of situations.

Therefore the double-staircase method was adopted for this experiment and employed in the following way. One staircase was started at the zero deviation and the other was started at the 3 degrees deviation. The staircases were run simultaneously by alternation. The subject was to say "yes" if she thought the target vehicle was heading toward the center of her right eye and "no" if it appeared to be doing otherwise. When the subject said "yes", the trajectory for the next trial of the same staircase would be one step (of 0.25 degrees) higher. When the subject said "no" it would be one step lower. Thus the two staircases would eventually meet and alternate between up and down steps within a certain range of trajectories. This range would be the 50% threshold area.

A subject was seated at the same position as in previous experiments, and covered her left eye with the eye-patch after reading the following set of instructions:

"When you look into the chamber you will find that your viewing field is obstructed by a shutter. Behind the shutter at some distance away is the miniature vehicle and it's red lights which you saw in the previous experiment.

Whenever the shutter opens, the target vehicle will start to move toward you. You will be able to watch it moving for about 2.5 seconds and then the shutter will close again.

It will either be moving straight towards the center of your right eye or it will be travelling on a trajectory such that if it kept going it would pass to the right side of your eye. In other words, it will either be coming straight toward you or going off on an angle (always to your right).

Your task is to tell me after the shutter closes each time whether it came straight toward you or not. Just call out "yes" if you thought it was heading for the center of your eye and "no" if it was not.

Do not hesitate to ask for a rest if you want one."

The double-staircase procedure was carried out for each of the six light configurations for each subject. For Subjects 1 and 2 the order in which the light configurations were tested was A, B, C, E, D, F (E coming before D, so that the triangular arrays were presented in order of increasing steepness). For Subjects 3 and 4 this order was reversed. Subjects had short rests between light configurations. Before testing began the subject was given examples of the zero and 3 degrees deviations.

Before each trial, the experimenter would first place the target vehicle in it's starting position and then set the plywood arm to the appropriate setting for the required trajectory. The lid of the chamber was then closed. Next the experimenter would simultaneously press the train starter button and raise the shutter, which by it's own noise gave the subject sufficient warning that a trial was beginning. The target vehicle then ran along the rails until stopped by the insulating tape placed on the rails. At this point the experimenter lowered the shutter to block the subject's view again. As soon as the shutter closed the subject responded.

As with the previous experiments, the only illumination available to the subject was the configuration of red lights. The visual field was otherwise one of complete darkness.

6. RESULTS: Experiment 4

6.1 Statistical analysis for the staircase method

Dixon and Massey (1983) describe methods for statistical comparison between different types of stimuli for the threshold results obtained using the staircase method. However, these methods, as Cornsweet (1962) points out, assume that " the response to each stimulus is independent of the preceding stimuli and preceding responses" (p.485). The types of example given by Dixon and Massey, such as testing the vibration sensitivity of explosives or the potency of insecticide doses (p. 426), do use procedures which satisfy that assumption, but in the application of the staircase method to psychology the trials are rarely independent, and the current case is certainly no exception.

It is not appropriate therefore to treat individual trials as data points for statistical comparison in the present case. What can be done, however, is to take the 50% threshold for each light configuration for each subject and compare these.

The 50% threshold is the mean value of the stimuli presented which fall into the range where subjects alternated randomly in their judgements, i.e., the range of stimulus values where subjects made judgements with only chance level consistency. However, this 'band' of uncertainty can vary substantially in width, so it is also useful to provide the standard deviations of these values.

In discussing the data obtained, the statistical comparison between light configurations for subjects will first be discussed, with reference to both the means and standard deviations of the threshold values. The results in terms of individual subjects will then be discussed.

6.2 Results

6.2.1 Group Results and statistical analysis

It is worth restating at this point that the 'threshold' refered to is the trajectory (specified in degrees of deviation) which the subject did not consistently judge as either coming straight toward her right eye or not coming straight toward her right eye; the trajectory at which they could not could not say what was happening.

As described in chapter 5, 2 subjects received the configuration testing blocks in the reverse order ,i.e., F to A instead of A to F. In the analysis of results, the order of testing of configurations was considered as a factor.

MANOVA procedures (SPSSX-2.1) were executed for both the mean and standard deviation values, with order of configuration presentation as a between-subjects factor and light configurations as six levels of a within-subject factor.

Table 16 shows the means of the threshold values, the units of measurement being degrees of deviation from the straight (zero deviation) trajectory. The data are presented separately according to order of presentation of light configurations for subjects, and also in a combined form for all subjects. The data is expressed in graphical form (without the combined data) in Figure 18. Table 17 shows the means of the standard deviations of the thresholds for each light configuration, again in combined form and seperately according to the order of configuration presentation for the subjects. This data is expressed in graphical form in Figure 19. We thus have analysis of two measures of the threshold for each light configuration; the mean (refered to as 'the threshold') and the standard deviation of each threshold 'band'.

Looking first at the mean threshold values, we find that the main effect of light configuration was significant ($F(5,10)= 8.31$, $p< .002$), a result that the seems to be due to the much lower thresholds for Configuration A than for other light configurations. The main effect of order of presentation was not significant ($F(1,2)= 11.52$, $p< .077$). There was, however, a significant interaction ($F(5,10)= 6.44$, $p< .006$). This appears to arise from the lower scores on Configurations A through D, but particularly on Configuration A, but not Configuration F, for subjects whose testing sequence was FDECBA. The two groups of subjects seem to have identical performance for configuration F.

With regard to the standard deviations (of individual thresholds), the main effect of light configuration was significant ($F(5,10)= 4.68$, $p< .018$). This would seem to be due to the lower standard deviations for Configurations A, B, and F. The main effect of order of presentation of Configurations was not significant($F(1,2)= 0.157$, $p<.730$). There was no significant interaction ($F(5,10)= 1.54$, $p< .262$).

Table 16: Mean values (deviation^{o}) of the 50% threshold values for configurations A-F

Order of Testing	Number of subjects	A	B	Configuration C	E	D	F
ABCEDF	2	1.32	1.79	1.60	1.76	1.61	1.31
FDECBA	2	0.29	0.78	0.75	1.08	1.09	1.33
combined	4	0.81	1.28	1.17	1.42	1.35	1.32

Table 17: Mean standard deviation (degrees) of thresholds for configurations A-F

Order of Testing	Number of Subjects	A	B	Configuration C	E	D	F
ABCEDF	2	.24	.16	.29	.26	.28	.23
FDECBA	2	.16	.22	.26	.28	.29	.19
combined	4	.20	.19	.27	.27	.28	.21

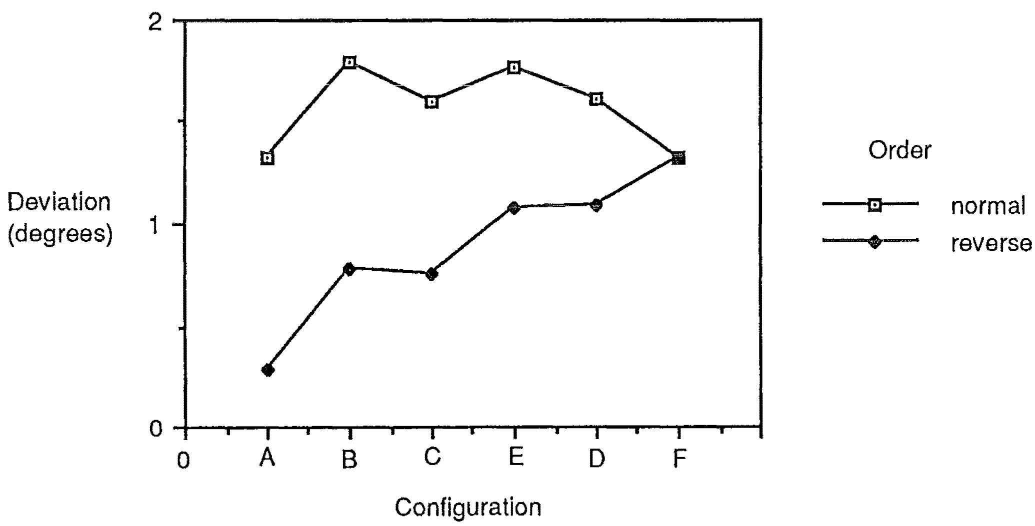


Figure 18: Threshold trajectories (degrees) for configurations A-F by order of presentation.

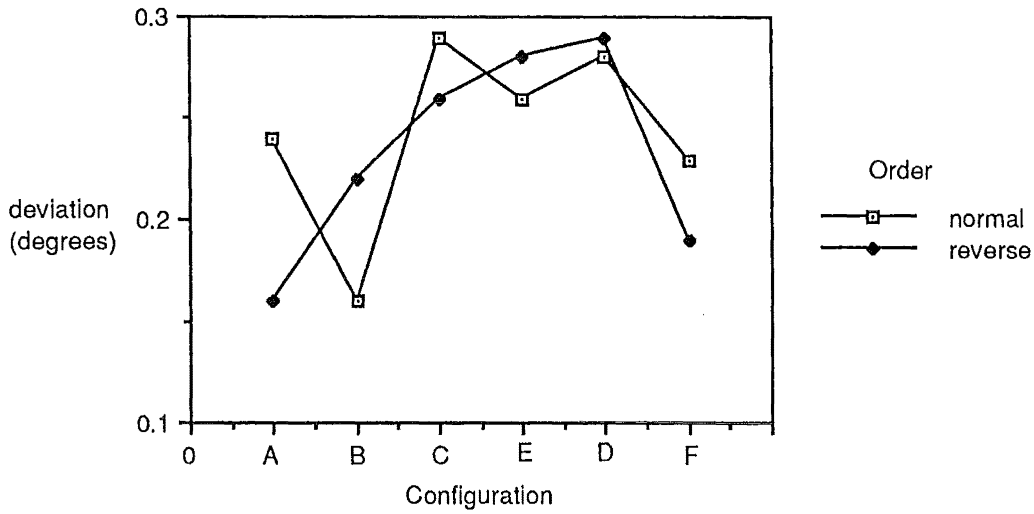


Figure 19: Mean standard deviations (degrees) of thresholds, for configurations A-F by order of presentation.

6.2.2. Individual Results

Some discussion of individual results is useful at this point to illustrate some of the above points.

Several of the double staircases executed are presented in the following pages as complete plots of all the trials carried out. The graphs for all other double staircases executed for this experiment are contained in Appendix 3. The staircases were alternated in presentation of stimuli but appear for convenience as simultaneous in the graph. Thus trial 10 on the horizontal axis refers to the tenth trial of both staircases or, as far as the subject was concerned, the 19th and 20th trials. There are thus six graphs for each subject.

Subjects 1, 3, and 4 produced a much lower threshold for Configuration A than for the other light configurations. Figures 20 and 21 show the plots of two staircases for Subject 3. The figures are for configurations A and B respectively. For subject 2 there is no real difference between configurations A, C, E, and D, but she did show a higher threshold for Configuration B than for Configuration A. The thresholds for Configuration A are much lower for Subjects 3 and 4, who received this configuration last, than for the other subjects. Subjects 3 and 4 also show obvious improvement with practice, although this improvement is not continous, i.e., it is not evident after each successive configuration. For Subject 3, there are really only two points where the decrease is substantial: between Configurations F and D, and between B and A. Subject 4 did not appear to improve while she was being tested with the triangular arrays (D, E, and F), but produced lower thresholds for configurations C and B, with an even lower one for Configuration A. Not all of the differences between light configurations would seem to be due to simple practice effects then.

Subject 4 appears to have performed exceedingly well in the case of Configuration A, with a threshold of just 0.13 degrees (Figure 22). However, such impressive performance arouses the suspicion that this subject might have guessed the method being used by the experimenter by the time she reached this, her last, configuration. However, none of the subjects, when questioned later, seemed to have much idea of how the testing procedure operated, other than that the task became more difficult as the testing for a given configuration proceeded. None of the subjects seemed to realise that their response in one trial determined the stimulus magnitude for a later trial. Furthermore, the thresholds that occured for this subject for the other 5 configurations are similar to those for subject 3 (Figure 23 shows Subject 4's performance for configuration E).

There are obviously considerable individual differences, even between subjects exposed to the same order of configuration tests. But 3 of the 4 subjects produced much lower thresholds for configuration A than for other configurations, with the remaining one being one of the subjects who was tested with configuration A first.

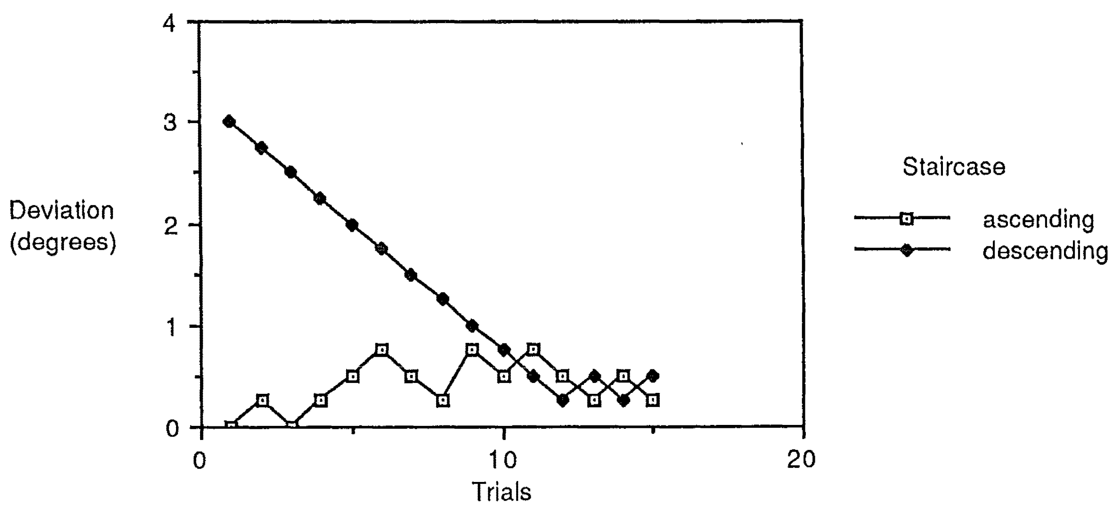


Figure 20: Results for Subject 3 when tested on Configuration A

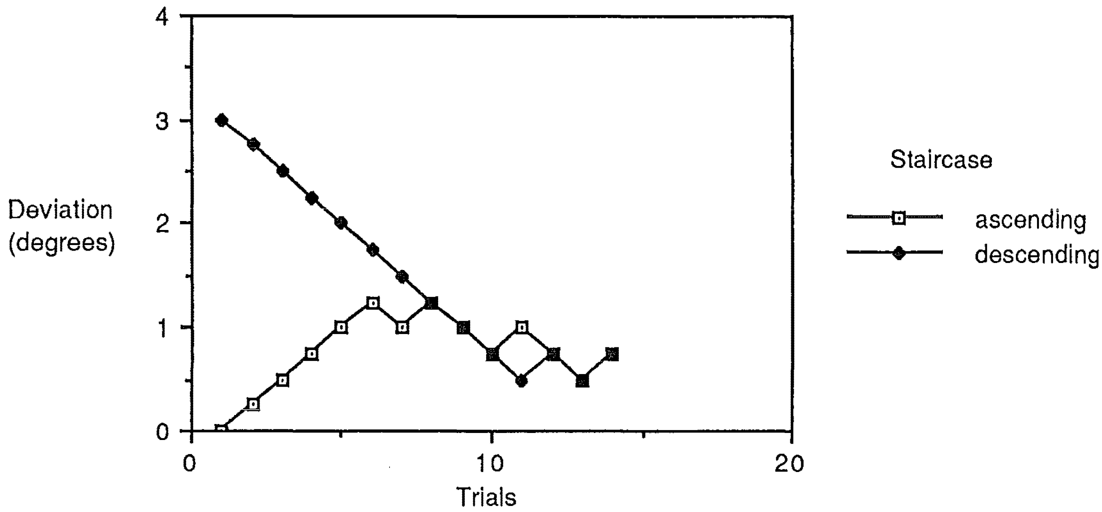


Figure 21: Results for subject 3 when tested on Configuration B

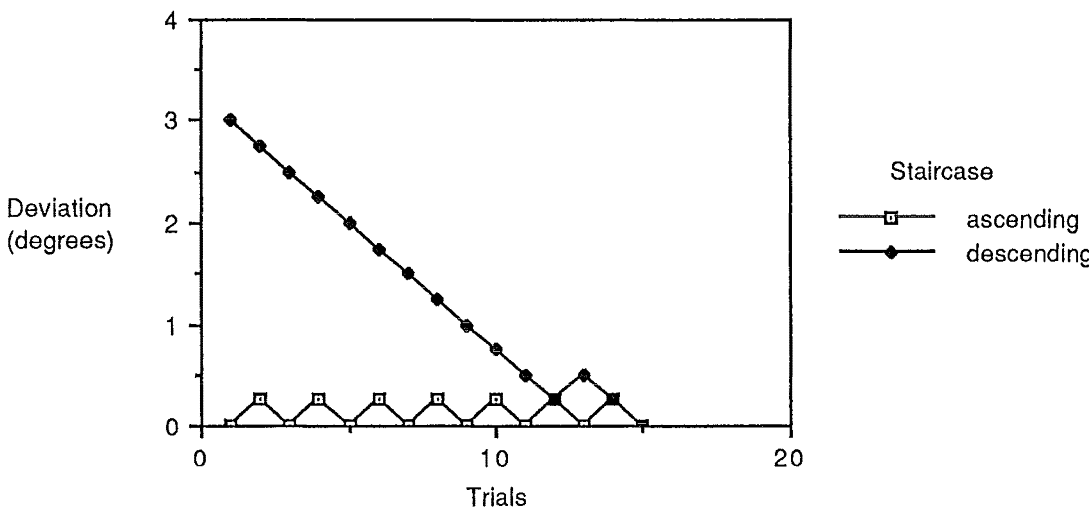


Figure 22: Results for subject 4 when tested on Configuration A

These individual differences are so substantial, and the sample size is so small, that one must be cautious about the results of the parametric statistical tests discussed earlier in this chapter. It is probable, for example, that subject 4's unusually low threshold value for configuration A exaggerated the apparent relative superiority of this light configuration for the group.

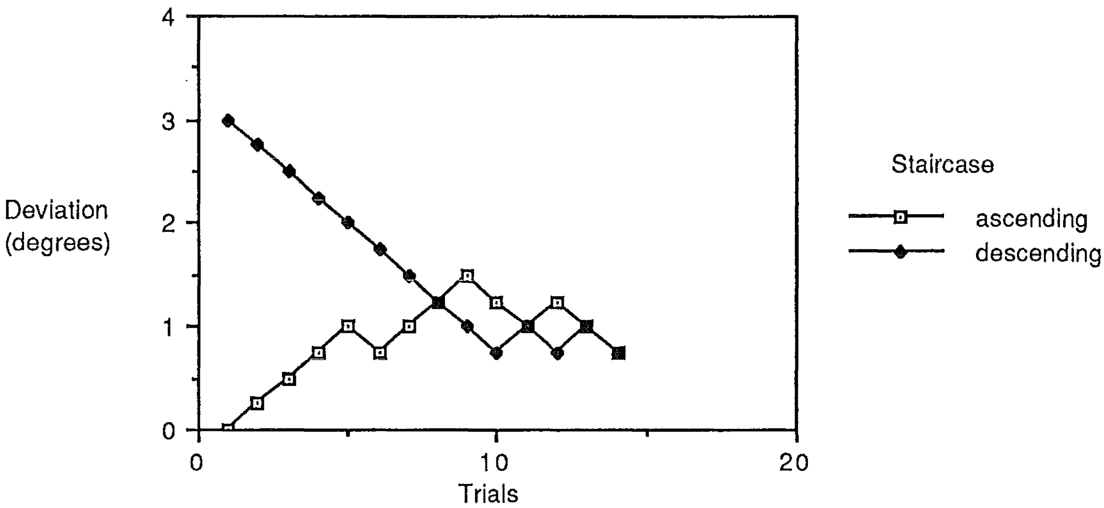


Figure 23: Results for Subject 4 when tested on Configuration E

6.3 Discussion

There was a significant difference between the light configurations for the threshold trajectory. It appears to be lower for Configuration A than for the other light configurations.

But the results are highly confounded by the order in which the different light configurations were presented to the subject. The main effect of order of presentation (normal versus reverse) approached but did not reach significance, and this may be due to the small sample size. There definitely was however a significant interaction between the light configurations and the order in which they were presented. Referring to Figure 18, it is noticable that the two subjects tested with the reverse presentation order produced generally lower thresholds and improved with practice (remembering that their last result appears at the left of the graph and the first result appears at the right, while the opposite is the case for the other two subjects). However, in the case of Configuration F their performance is the same as for the other two subjects. The two subjects receiving the normal presentation order produced about the same thresholds for Configuration F as they did for Configuration A, but produced apparently higher thresholds for the other light configurations.

The most appropriate explanation for these trends involves a combination of the practice effects that emerged and the apparently much lower thresholds for Configuration A than for other configurations. If we assume that Configuration A did afford lower thresholds than the others, among which there were no differences, then the results for the subjects receiving the reverse order of configuration presentation can be interpreted as general improvement with practice (Figure 18 being read right to left for their results) combined with an inherently easier task for Configuration A. The two subjects who received the configurations in the normal order, on the other hand, were tested on the easiest one without practice and thus do not seemed to have improved with practice at first.

But such an explanation does not account for the finding that both groups produced the same threshold for configuration F even though this was the first one tested for one pair of subjects and the last one for the other pair. One possibility was that the two subjects assigned to the reverse presentation order were simply more sensitive to begin with. Another is that practice was more effective if the more complex light configurations came earlier. Nevertheless, the superiority of Configuration A seems to stand out.

As mentioned earlier, the standard deviations provide an indication of the width of the 50% threshold 'band', or the size of the range of trajectories which the subject is inconsistent in making judgements about.

The standard deviations were not affected by practice, but they do appear to differ between the different light configurations. It appears from Figure 19 that configurations A, B, and F offered narrower bands of threshold stimuli. The differences are of course slight, amounting to less than 0.1 degrees.

6.4 Key results and conclusions

Despite the effects of practice, subjects appear to have found light Configuration A, the single red light, the best one in terms of accuracy of judging whether or not the target vehicle was coming straight towards their right eye. Therefore the hypothesis, that a light configuration which includes both horizontal and vertical substantial components would afford the best information about the relative trajectory of the object carrying it, was not supported. Nor did the results support the more mundane expectation that a pair of lights would be better than one for this purpose.

7. DISCUSSION AND CONCLUSIONS

7.1 Validity of the simulation

There are three major questions which one might ask regarding the validity of the simulation: (a) Were the subjects actually using visual information? (b) Were they using the type of visual information that the experiments were concerned with? (c) Was the scaling-down effective and valid in optical terms?

In answer to the first question, it seems that subjects were responding to visual information even though subtle nonvisual information (produced by the movement of the target vehicle) was available. It was demonstrated in Experiment 3 (where subjects had to perform the same task as in Experiments 1(a) through 2(b) but had no visual information) that subjects were more sensitive to movement when the 'taillights' were activated than when there was only nonvisual information. The only exception was for movement by the target vehicle from greater initial distances when only the single 'taillight' was present on the target vehicle: in this case there was no difference in subject performance between the 'taillight'-on and 'taillight'-off conditions. Given that the combination of large initial distance and a single 'taillight' was the most difficult for subjects, we can assume that for most conditions, and definitely all conditions where more than one 'taillight' was present, visual information was being used rather than (or preferentially to) nonvisual information. It should also be remembered that the subjects who participated in Experiment 3 were specifically instructed to respond to noise information, whereas subjects in Experiments 1(a) through 2(b) were not told about any possibility of noise information, and were in fact instructed to respond when they 'saw' the target vehicle moving. Thus we would expect that the actual effectiveness of noise information to be even less in experiments 1(a) through 2(b) than the results of experiment 3 would suggest.

Therefore it is very unlikely that subjects were responding to something other than visual information. But were they responding to the type of visual information that was the subject of analysis? Several subjects suggested that other sources of visual information signifying motion were available to them, such as lateral 'wobbling' by the lights when the target vehicle was moving and light shining from the red LEDs onto the rails. How useful was this information to such subjects?

Few reported seeing such 'wobbling' or reflected light and it would seem that such information would be vastly inferior to that of actual optical expansion/contraction of the light configuration on the target vehicle as it approaches/recedes. The fact that, for experiments 1(a)-2(b), there was a significant difference between Configuration A and the other configurations in terms of subject response demonstrated this. Configuration A was the only one which did did not subtend a substantial visual angle, but it would also have provided such visual motion information as lateral 'wobbling' or light reflecting on the rails (if these had in fact occurred). But subjects' performance was much worse for this configuration than for others. Therefore it seems unlikely that subjects were using these sources of visual information.

Was the scaling-down involved in the simulation valid? It appears that it was, because subjects (in experiment 1(a)) who viewed the target vehicle with both eyes were much better at detecting relative motion by the target vehicle than were subjects who viewed it with one eye. In a full-scale, real-world setting we would not expect binocular vision to give such an advantage because the real depth is much greater. In the simulation it appears that subjects viewing with both eyes had an advantage because the real depth of the simulation environment was of a small amount such that they were able to use binocular disparity as well as monocular visual information. Subjects who viewed the simulation with one eye performed less successfully, since they were not able to perceive change of real depth in the same way. This suggests that the simulation, when viewed with one eye, was an effective and optically valid representation of the real-world dimensions and visual situation. Subjects were responding to visual information, and to the type of visual information being manipulated. Also it seems that real-world distance/size/velocity relationships were preserved in the scaling-down which the simulation involved.

It might be argued that the apparatus used, which essentially comprised a model train moving along rails through a darkened environment, leant itself by nature of design to such problems as noise, and momentum of the target vehicle which ensured a small amount of movement after the subject had responded. But the device is perhaps an improvement on those of Potter (1961) and Mortimer (1972). Potter's target was pushed along by an experimenter positioned under the table, while Mortimer's target vehicle was operated via a hand-crank device. While a computer simulation might have overcome potential difficulties such as noise, it would not have produced the actual depth which was desirable in this experiment.

7.2 The detection of relative motion

7.2.1 Effects of differing light configurations

The results of Experiments 1(a) and 2(b) indicated that relative motion was significantly more difficult to detect when only one taillight was present than when two or more lights were present. In Experiment 1(a), however, this difference occurred at the 2- and 3-second simulated headways but not the shortest headway. It would seem that there was something unusual occurring at this nearest distance, an effect which seems to arise from the nature of the light configurations themselves. It appears that either the angular velocity of a pair or three lights was no better than information available from a single light at this shortest distance, or that subjects attended to size/brightness information rather than angular velocity information at this distance. The observation that $\Delta D/D$ fractions were twice as large for the shortest distance as for the other distances suggests that the latter was the case.

However there was no difference between the traditional two-light array and the row of three lights or the equilateral triangle of lights. The results of these experiments thus indicated that adding a vertical visual angular component to the array or increasing the number of lights did not affect thresholds of relative motion or distance change.

In Experiments 1(b) and 2(b) the four different tri-light configurations (three lights in a row, a flat triangle, an equilateral triangle, and a steep triangle) were tested. Again there was no difference between the light configurations, with the exception of an interesting interaction which occurred in Experiment 1(b), where three initial distances were used. At the nearest distance and the middle distance, motion by the target vehicle was harder to detect when it carried light configuration E than when it carried one of the other tri-light configurations. However, at the furtherest distance, this light configuration enabled subjects to detect motion sooner than did the other three light configurations.

That motion by the flatter triangle is harder to detect than motion by an equilateral or steeper triangle of the same horizontal width is expected, since the flatter triangle has a smaller vertical visual angle and thus would have to move further for change in this visual angle to reach threshold level. But if this were the case, then the flat triangle should not have been inferior to the row of lights, which it was, for the middle and near distances. Furthermore, it should not have been the best configuration for the futherest distance.

One possible explanation for this is that vertical visual angular information might only have been of use at shorter distances. Thus the triangular arrays presenting greater vertical visual angles were more effective at shorter distances, but showed no superiority at longer distances. This does not, however, explain why the row of three lights seemed to be just as effective, overall, as the triangles, unless one assumes that subjects are using different but equally effective information when observing a row of lights rather than a triangle. Such an assumption would also explain the lack of a difference between configurations B, C, and D in Experiments 1(a) and 2(a).

Generally, the findings do not support those of Mortimer (1972), or the closely related studies of Potter (1961) and Hoppe and Lauer (1951). Both Hoppe and Lauer (1951) and Potter (1961) employed solid-shape reflectors as stimuli, however, and may have thus been offering more meaningful 'wholes' as stimuli to their subjects. Also, while Potter (1961) used a method similar to that employed in the current study, Hoppe and Lauer's (1951) method corresponded more to a signal detection paradigm, which may have been testing different abilities or the same abilities in a different way. But Mortimer (1972) himself did employ triangles and pairs of red 'taillights', and found the triangle to be significantly more effective than a pair of lights in signalling headway change. The current study did not find such a result.

As was mentioned in Chapter 1, Mortimer provided no test for the possibility that the triangular and square arrays were better than the pair, and the square better than the triangle, simply because he was increasing the number of lights in the configuration. However, the present study found no difference between a pair of two lights and a row of three lights, so the numerosity/density of lights seems unlikely to have been the source of differences between configurations.

In the current experiment, red LEDs were used as the 'taillights' so as to create point-source components in the light configuration. In Mortimer's laboratory study, the 'taillights' were in fact cut-out holes (covered with red filters) in a box containing a light source. With such an arrangement, additional movement information might have been available in the form of changing patterns of light reaching the eye through the cut-outs as the distance between the eye and the light source inside the box changed. However, Mortimer found the same results in on-road tests where real taillights were used.

Mortimer found that a square was better than a rectangle. It is tempting to believe that significant differences might have emerged in the present study had squares been used instead of triangles. The aim of this study was, however, to examine the effect of adding a substantial vertical component to the light configuration. A triangle serves this purpose as well as a square, and does so without adding as many lights to the existing configuration, so it should be less likely to create differences merely through changes to numerosity/density in the configuration. A triangular array does not of course offer any visual angles (subtended by any two lights) which are strictly vertical, while a square does. But, given that Probst et al. (1987) found lower thresholds for horizontal visual angular change than for vertical visual angular change, one might expect semi-vertical visual angles to allow greater sensitivity than purely vertical ones. Thus there are a number of reasons why a triangular array was sufficient for the present study.

Mortimer used lower relative velocities than the present study, especially in his lab simulation. As mentioned in chapter 1, he may have thus been tapping something other than simple motion perception processes, such as memory for position or apparent size, in the laboratory simulation. But the relative velocities in the field study were somewhat higher, involving actual 'coasting' by lead cars. Nevertheless it did take considerably longer for threshold distance change to take place than was the case in the present study, so perhaps such a distance memory process was involved. Potter (1961) used target sizes and approach speeds very similar to those in the present study, however, and found significant differences between the types of reflector shapes.

Probst et al. (1987) argue that people prefer horizontal rather than vertical visual angular information. Given that all the multi-light configurations in the present study subtended the same horizontal visual angle, is it posible that subjects were only responding to changes in the horizontal visual angle, without attending to the vertical or semi-vertical visual angles? Mortimer (1972) used a distraction task while the current study did not, so it could be argued that his subjects faced a more difficult task in detecting relative motion by the taillights. Perhaps subjects in the current experiment, being able to attend to the lead vehicle more, were able to respond effectively to just the horizontal visual angle. Mortimer's subjects, on the other hand, would have needed more information from shorter fixations on the target lights, and thus may have been helped by the additional information presented in the triangular and square light arrays. Thus the task would have been made easier by the addition of a vertical component to the light configuration.

This raises an interesting possibility. It was expected, as discussed in Chapter 1, that the triangular light configuration would afford greater sensitivity to changing headway than the traditional pair of lights in a 'minimal stimulus' situation, one in which the driver is following another car along a dark road at night. But, given that Mortimer (1972) found the expected effect while employing a distraction task whereas the present study did not, it would seem that the alternative light configurations might only be of use when there are substantial competing demands for the driver's attention, with the effect that he/she must derive as much information as possible from the from shorter/fewer fixations on the target vehicle. Haines (1989) found that his subjects were less sensitive to relative motion by another (simulated) spacecraft when the Crew Optical Alignment Sight (COAS) was present than when it was not. He reasoned that this was because the subject's immediate environment created many attentional demands, allowing only limited attendance to the target object. Thus, under certain conditions, potentially distracting information (which the COAS was for this particular task) makes motion detection harder. Perhaps Mortimer (1972) had found something that made the task easier when there were competing demands on attention. While there have been some studies which have examined the effect of exposure duration on motion thresholds (Todosiev & Fenton, 1966; Harvey & Michon, 1974), none of these compared different light arrangements such as those tested in the current study and by Mortimer (1972). The possibility that triangular or square light arrays are more effective than a pair of lights when the following driver can only fixate on them for very short durations is one that has yet to be examined.

The interaction which was found in Experiment 1(b) deserves further mention because it indicated that, for certain distances, there was an effect of the amount of vertical extent in a triangle of lights. However, the row of three lights seemed to produce results which were among the average of those produced by the triangles. It appears that subjects might have responded in different ways when a triangle rather than a pair or row of lights was present, but that the two ways of responding were equally effective. However, when one triangle is tested against another, performance appears to be affected by the amount of vertical extent in the triangle.

7.2.2 Motion detection and initial distance

In Experiments 1(a) and 1(b), three initial distances were employed, corresponding to 1-, 2-, and 3-second temporal headways for cars travelling at 50km/hr. In Experiment 2(b) there were two initial distances, which fell between the outer values used in Experiments 1(a) and 1(b).

It was found that, for all light configurations generally, the minimum detectable distance change increased with initial distance. This corresponds to the findings of all other studies on headway change detection. This trend occurred for the single-light configuration as well as for all the multi-light arrangements, so this rule holds true for the size-brightness 'cue' as well as optical expansion/contraction information.

In Experiment 1(a), configfurations B, C, and D all showed approximately the same pattern of results for the monocular vision group. But while minimum detectable distance change increases with initial distance, the relationship is not so linear that it may be described by a single Weber fraction. While the change of distance/initial distance (ΔD/D) ratio was the same for the 2- and 3-second headways, it was somewhat larger for the 1-second headway. A similar trend emerged for all four light configurations (C, E, D, and F) in Experiment 1(b). Thus at a simulated distance of 13.89m, the actual detectable change in distance is smaller than for a simulated distance of 27.78m, but is a greater fraction of the initial headway.

If we convert, for configurations B through F, the detectable distance change into change in visual angle, we find (on the basis of the group means only, of course) that the minimum detectable visual angular change decreases with increasing distance, but the change of visual angle/initial angle fraction (ΔØ/Ø) is the same for the 2- and 3-second headways. However it is much larger for the 1-second headway.

These trends conflict with the reports of other researchers. Haines (1989) found that ΔØ/Ø fractions decreased with decreasing initial distance (increasing initial visual angle), and refers to similar trends found by other researchers. Harvey and Michon (1974) reported a similar trend. With regard to Weber fractions for distance change, Mortimer (1972) suggested a single fraction applicable to all initial distances, while it is unclear from the data of Rockwell (1972a) whether a single Weber fraction is appropriate.

Why was the fraction much larger for the nearest distance? It is possible that the addition of the same basic reaction time to all three conditions made the detectable distance change for the nearest condition seem greater in relation to the others than it actually was, but this is not adequate to explain a Weber fraction for the 1-second headway which is almost twice as large as that for the 2-second headway. Also it does not explain why the $\Delta D/D$ fractions were the same for the 2- and 3-second simulated headways.

Interestingly, in Experiment 1(a), the Weber fraction of distance change for Light configuration A (the single light) is also larger for the 1-second headway than for the 2-second headway, but the difference is much less (noting that there was no difference between light configuration A and the others at the nearest distance). This would suggest that the answer to this question cannot be found in terms of simple reaction times themselves, but had something to do with the light configurations and the initial distance from the observer at which they are situated.

Actual minimum detectable distance changes are nevertheless smaller for the nearest distance than for the others.

7.2.3 Motion detection and direction of movement

In experiments 2(a) and 2(b), the target vehicle moved either toward or away from the observer. Contrary to the findings of almost all other studies, there was no effect of direction of relative motion on minimum detectable distance change.

At very large initial distances, the effect of direction of motion does not occur (Harvey & Michon, 1974). However, the distances simulated in the present study fall within the range where effects of direction of relative motion have been found to occur. Furthermore, in Experiment 2(b) a second, much shorter initial distance was employed as a control condition, but no effect of direction was found. Interestingly, when the means of distance change are converted into visual angular displacements there is (on the basis of the mean values only) no difference between the two directions of motion, as was found by Harvey and Michon (1974). But this is because equal angular displacements for both directions of motion correspond to greater distance change for movement away from the observer, so it is inconsistent to say that there is no direction-dependent difference in both distance change and visual angular change terms.

However, the differences for motion detection that arise from the direction of motion can be quite small in actual distance, velocity, angular displacement, and angular velocity terms. It may be the case that the apparatus and measures used in the current experiment were insufficiently sensitive to detect the difference between directions of relative motion. Laboratory simulations employed by Todosiev and Fenton (1966) and Harvey and Michon (1974) used considerably more sensitive measures, but they did not create real motion in depth, which was a desirable feature of the current study.

Evans and Rothery (1974) suggested that the direction effect arises from a safety bias; i.e. that people are biased towards detecting motion toward them for safety reasons. This explanation is applicable to the findings of other on-road research. In the present study, however, subjects would have had no need for such a safety bias.

It is possible that lower thresholds for motion toward the observer are a two-step phenomenon; (a) there is the basic trigonometric fact that looming objects change in subtended visual angle more than zooming objects, and (b) there is the 'safety bias' of on-road drivers and passengers. The present study may not have been sensitive to small differences attributable to trigonometric factors and, at the same time, gave subjects no reason for a 'safety bias'. This could explain why no effect of direction of relative motion was found.

Mortimer (1972) did not report an effect of direction of relative motion, but he only used both directions of relative motion in the laboratory simulation (the field tests only involved 'toward' relative motion). Perhaps he did not find a direction-dependent difference for the same reasons.

There is another possible reason why no effect of direction of motion was found. In the current study, as in Mortimer's, the onset of motion was potentially visible to subjects. The subjects of Evans and Rothery (1974) and Harvey and Michon (1974), on the other hand, were given glimpses which did not include the onset and/or end of motion. Todosiev and Fenton (1966) allowed subjects to see the onset and end of motion, but again only allowed glimpses of the 'taillights'. In the current study, subjects continually viewed the relevant visual environment and were required to respond as soon as they detected the onset of motion by the target vehicle, unlike the subjects in the abovementioned studies who made post-stimulus judgements. Is it possible that direction-dependent effects are reduced or removed when subjects can see the onset of relative motion? The literature is mixed with regard to this possibility; Torf and Duckstein (1966), Mortimer (1972), and Probst et al. (1984, 1986,

1987) used similar procedures to that employed in the current study (except that Mortimer provided a distraction task); subjects viewed the target vehicle continuously and were required to detect motion as it happened. Torf and Duckstein found that 'away' motion was easier to detect than 'toward' motion, while Probst et al. found that 'toward' motion was easier to detect than 'away' motion. Mortimer and the current study found no difference between directions. Thus it need not neccessarily be the case that 'toward' motion is easier to detect than 'away' motion when we have a laboratory simulation involving continuous viewing of the target, visual availability of motion onset, and a response during the event.

Another factor to be considered concerns the light configurations themselves. Mortimer's is the only previous study which has tested such alternative 'taillight' configurations in examining the ability of subjects to detect changing headways. It is possible that triangular or square arrays, or even a row of three lights (as for Configuration C in the current study), confound the direction effect in some way. However both studies also simulated the traditional pair of lights and found no motion direction effect, whereas Todosiev and Fenton (1966) and Harvey and Michon (1974) did find a direction effect using simulations of a pair of taillights. However, as was mentioned previously, those studies differed greatly from the current one in a number of ways, one of these being that they did not use real motion in depth in their simulations, so that their 'taillights' did not change in size or brightness as they 'approached' or 'receded'. While Janssen, Harvey, and Michon (1976) did eventually conduct an on-road test in darkness, they used the same procedure as was used in the laboratory (i.e., fixed durations of exposure to established relative motion, and post-stimulus forced-choice response by subjects). Therefore even this experiment was still very different to the present ones.

Therefore, while no effect of direction of motion on thresholds of distance change was found, there are a number of possible reasons why it did not occur in this study whereas it did in many others.

7.2.4 Threshold values obtained

How does the data compare with that obtained by other researchers? Given that there was no effect of direction of motion, there were, across the various experiments, five initial distances from which relative motion began: 560, 743, 1110, 1330, and 1670mm from the observer's eye. Configuration B, the light array most represented in real-world conditions, was tested at all of these except the 743mm distance. For the four remaining initial distances, the real world distances that were simulated were (not including the 743mm distance) 13.89, 27.78, 33.25, and 41.75m respectively. For these four tested distances, the minimum detectable distance change for this light configuration was estimated (by deducting the amount of distance the target vehicle would have travelled after the subject had responded, a value derived in the manner described in Appendix 1) to be approximately 77, 96, 105, and 128mm respectively. The $\Delta D/D$ fractions were thus approximately 0.14, 0.09, 0.08, and 0.08 respectively. Note, as mentioned earlier, that beyond the nearest initial distance the obtained fraction is fairly constant. Since there was no difference between configuration B and configurations C-F, these 'thresholds' and fractions apply equally for all the multi-light arrays.

How do these values compare with those found by other researchers? Certainly the Weber fractions are much lower than those given by Mortimer (1972), who produced fractions between 0.12 and 0.17. They are also lower than the 0.1 to 0.2 fraction suggested by Rockwell (1972), although he gave some examples of threshold distance change for initial distances similar to those simulated in this study, and those examples, given in Chapter 1 of this thesis, do not differ greatly from what was found in the current study; For example, he quoted a closure threshold of 10 ft for a headway of 100 ft, while the current study found a detectable distance change equivalent to approximately 2.4 m (8 ft) for an initial distance of 27.78 m (92.5 ft). These results do not differ greatly, and it is likely that Rockwell's subjects faced a slightly more difficult task than the subjects in the present experiment.

A distance change fraction of 0.11 was derived from an example given by Evans and Rothery (1974). This is also higher than the fractions indicated by the current study. However the fractions obtained in the current study are much higher than than those which were derived from the relative velocity threshold formulae given by Janssen et al. (1976), which indicated distance change fractions of 0.04 to 0.05. As mentioned earlier, subjects in those experiments performed a somewhat different type of task.

Hoffman (1968) provided data on the threshold change of distance as a function of initial distance for the data of Braunstein and Laughery (1964). This data indicated a Weber fraction of 0.08 to 0.09 for decreasing headways. This is quite similar to the findings of the present study. He also provided similar data for the studies of Bierley

(1963) and Torf and Duckstein (1966). For relative motion towards the observer, Bierley's data indicates a distance change fraction of 0.025. In the case of Torf and Duckstein, the on-road data indicates a fraction of 0.2 while the laboratory experiment data indicates a fraction of 0.09.

The minimum detectable distance change estimates (i.e., with estimated post-response travel distance deducted) from experiments 1(a) through 2(b) were converted into angular displacement and initial visual angular terms, thus giving an approximate indication of the amounts of visual angular change reqired for motion detection. For the initial distances of 560, 1110, 1330, and 1670mm, the initial (largest possible) visual angles subtended by configurations B through E were 5.3, 2.7, 2.2, and 1.8 degrees. The approximate changes in visual angle required for detection of motion were 0.9 , 0.25 , 0.2 , and 0.1 degrees for the four initial visual angles respectively. Thus $\Delta\varnothing/\varnothing$ fractions would be 0.16, 0.09, 0.09, and 0.06 for the four distances respectively.

How do these compare with the findings of other researchers? Haines (1989), who looked at astronauts' perception of relative motion by another spacecraft, found that the "orbiter image must expand by from 4 to 11% of it's original size in order to be correctly perceived as having approached" (p. 149). The angular change fractions for the current study fit within that range, with the exception of the fraction for the shortest initial distance, which is, as pointed out earlier, unusually large. Hoffman (1968) suggested fractions of about 0.11 on the basis of Braunstein and Laughery's (1964) data. Note that Braunstein and Laughery used longer headways than those simulated in the current study, so the distance-angular size relationship is slightly different. Harvey and Michon (1974) found that such fractions ranged widely, from 0.04 to 0.2, depending on initial visual angle and exposure time. The current estimates fall within this range.

There is considerable variance in the literature with regard to what the thresholds of distance change and visual angular displacement actually are. The estimates obtained in the current study fall within the range of findings that have emerged, but are at the lower end of this range. This may be because the task was perhaps easier than that which confronted subjects in some other studies.

7.2.5 Sex differences

In Experiment 2(b) males performed significantly better than females. This effect was consistent across all four light configurations, both directions of relative motion, and both initial distances. However, no sex differences emerged in Experiments 1(a) and 1(b), and Experiment 1(b) employed the same set of light configurations.

Why were males apparently more accurate than females in this experiment? Mcleod and Ross (1983) found that males were more accurate than females in estimating time-to-collision, although all subjects substantially underestimated the time. They suggested that this might be due to 'riskier' behaviour by males. But in the present study, male subjects' behaviour could actually be interpreted as 'safer' behaviour, since they detected headway changes sooner than the females, although this assumes the desired generalisation to the real world. In terms of the experiment itself, were the males taking more risks? There were very few anticipatory responses (less than one per subject) and males made no more or less than females for the group as a whole. It is possible, nevertheless, that they may have adopted a more liberal response criterion than females.

Mcleod and Ross (1983) also suggest that the sex difference in their experiment might have been due to sex differences in spatial processing generally. But no difference was found in Experiments 1(a) and 1(b) of the current study, which made similar demands on subjects. However, while Experiments 1(b) and 2(b) employed the same sets of light configurations, in Experiment 1(b) subjects would have realised quickly (as in Experiment 1(a)) that there was only one direction of relative motion, albeit from three possible initial distances. Subjects in Experiment 2(b) were exposed to only one initial distance but there were two possible directions of motion, which occurred randomly. Thus there was potentially more uncertainty in Experiment 2(b). Perhaps this increase in uncertainty brought out sex differences in response criterion.

7.3 Discrimination of relative trajectory

7.3.1 Effects of practice

In Experiment 4, each of the four subjects was tested using Cornsweet's (1962) double staircase method of threshold determination. The aim was to find the relative trajectory of target vehicle motion which they could not consistently judge as being either a collision or a noncollision course trajectory. Since there were six light configurations, each subject underwent six double-staircase series (i.e., six ascending and six descending series).

It is quite evident that subjects benefited from practice. Subjects who were tested on the light configurations in the order of A, B, C, E, D, F did not appear to show improvement with practice while those who were tested with the order of configuration presentation being F, D, E, C, B, A did show great improvement with practice. However, the fact that practice effects were obtained for one order of configuration presentation but not the other indicates that similarities and/or differences between light configurations had some effect on whether or not subjects improved with practice.

7.3.2 Effects of light configuration

Three out of four of the subjects were more sensitive to deviation from a collision course by the target vehicle when it carried only one light than when it carried two or more lights. This difference emerges above the practice effects; subjects who received the F through A testing order improved between Configurations B and A, but the two subjects tested with the 'normal' order worsened between Configurations A and B. Thus the reason why subjects receiving the A through F order of configurations did not show improvement with practice appears to be that they were tested on the inherently more informative configuration first.

There was, however, no real difference between the two- and three-light arrays, or between the different three-light arrays. Thus it would appear on the basis of this experiment that the additional optical information specifying relative trajectory which is created by the addition of a third light (either to make three lights in a row or a triangle of lights) is of no practical use to the observer. Evidently the supplementary information does not lead to a noticable improvement in subject performance.

Why was the relative trajectory of a single light more readily perceived than the relative trajectory of a set of lights? A single light is probably better than a pair or three lights in terms of 'target drift' (Warren et al., 1988) information. But if an observer can respond to leftward or rightward optical drift by a single light in making relative trajectory judgements, then surely that person should be able to do the same with the light in a pair or triangle of lights which is nearest to his/her line of travel. Furthermore it is reasonable to expect that the presence of an extra light(s) would lessen the ambiguity in the drift of the nearest light, thus making the observer more sensitive to target drift. Therefore the 'target drift' hypothesis does not explain why a single light was better than two.

However, if the source of information about relative trajectory was the movement of the 'taillights' relative to the focus of expansion, then perhaps one light would be better than a multi-light array. This is because one light is a much smaller 'whole' than several lights, and a smaller object moves away from the focus of expansion more clearly than a larger one if it is on a non-collision course with the observer; the difference between the observer's line of travel and the line of travel which would lead to the object marked by the light would be more distinct. Of course, there was no focus of expansion for the observer in the current laboratory study since she was stationary and the only visual information available was the movement of the red lights, but there was an equivalent (to the focus of expansion) if she fixated in the region of the visual field in which the lights originally appeared to be, and continued to fixate on that area as the target lights moved. She would find that the lights, if moving on a non-collision course as they came closer, would move out of that region as they came toward her, in the way that they would move away from the focus of expansion if she herself was moving through the environment on a non-collision course with the lights.

Perhaps subjects were using different information when two or more lights were present, such as the symmetry/asymmetry of the expansion of the image of the light configuration; such information is not really available when there is only one 'taillight'. It would appear that the two types of information (movement relative to the focus of expansion and symmetry/asymmetry of expansion) are each useful for different conditions, depending on whether one or several 'taillights' are present on the rear of the 'lead vehicle'.

7.3.3 Sensitivity to relative trajectory

A collision-course was a zero relative trajectory. Therefore when the target vehicle is described as deviating from a collision course by 2 degrees, it is meant that the angular difference (at the point of origin of motion) between a collision course and the actual trajectory is 2 degrees. That is a description of the actual events in the simulator; in the real world, the above example represents a difference of 2 degrees between the observer's line of travel and the slower moving lead vehicle's line of travel.

For all subjects and all light configurations the 50% threshold value was between 0.8 and 1.4 degrees, although for some configurations the two subjects receiving light configurations in the A through F order produced 50% thresholds of up to 1.75 degrees, while one subject tested with the order of configurations being F through A produced a thresold for configuration A (the single light) of just 0.13 degrees.

The 50% threshold for configuration A was about 0.8 degrees. Thresholds for the other configurations were in the region of 1.2 to 1.4 degrees. As standard deviations of the 50% thresholds were 0.2 to 0.3 degrees for all light configurations, it appears that, if we take the group means as the guideline, then a relative trajectory is consistently perceived as a non-collision course if it deviates from the actual collision course by, in the case of the single 'taillight', 1 degree, and in the case of the multi-light configurations, 1.45 to 1.65 degrees. Given that these results were confounded by practice effects, thresholds might be somewhat higher in a situation where there had been no practice (such as in a between-subjects design). But drivers are very experienced at overtaking other cars at night, so we might on the contrary expect thresholds to be much lower in the real-world situation. Cutting (1986) argues that heading perception accuracy of 1 degree is necessary to drive safely. One would expect many more 'glancing blows' during overtaking than actually occur if accuracy in perceiving heading relative to an object was as poor as 1.75 to 2 degrees.

The obtained thresholds are nevertheless quite low. Cutting (1986) interpreted Riemersma's (1981) results as indicating a heading sensitivity of 1 degree. Warren et al. (1988) suggest heading thresholds (75% accuracy) of 1.2 degrees, with thresholds being as low as 0.66 degrees under certain conditions. The results of the current experiment are not greatly different from these.

However, in the most relevant study, that of Micheals and Cozan (1963), drivers displaced laterally from a roadside object that was 2 degrees or more from their line of travel. The lateral displacements were not extreme changes but gradual and subtle ones, so it is unlikely that the subjects actually believed that they were on a collision course with the roadside object (which was never actually in their path). But it was nevertheless evident that such objects outside the collision-course zone may affect driver steering behaviour. While the present study and those of Riemersma (1981) and Warren et al. (1988) required subjects to make judgements about heading relative to an object (in the present case) or the ground (in the previous cases), the work of Micheals and Cozan (1963) was concerned with more subtle factors affecting driver behaviour, although the visual principles involved are the same. What is most likely the case is that drivers are able to judge heading within 1 degree and heading relative to particular objects within 1 degree, but are nevertheless affected in a subtle sense by objects in the environment which are clearly outside but still near their line of travel.

7.3.4 Safety versus accuracy

The subjects made the most accurate judgements about relative trajectory when the target vehicle displayed only one 'taillight'. But this does not mean that drivers would actually be better at overtaking other cars in darkness if the other car carried only one taillight. Such a taillight would have to be mounted in the center of the rear of the vehicle to best signify the car's position in relation to the following driver's line of travel, and unfortunately this would mean that while an overtaking driver might be very sensitive to the position of the light itself, he/she would not be sensitive to the outer edges of the lead car. In other words, the overtaking driver might avoid the tail/brakelight but still hit the rear of the car. Also, it is preferable that there be two taillights rather than one for the purpose of headway change detection. Detection of headway change is often essential before relative trajectory judgements are required. If drivers are less accurate in judging relative trajectory when there are two taillights instead of one, then presumably they allow more (lateral) room for error when overtaking than they would if cars carried only one taillight. Such a tendency is, within limits, in the direction of increased safety.

Micheals and Cozan (1963) found that drivers' lateral displacement away from the roadside object was greater if the base of the triangular object, rather than the apex, was nearest the driver's line of travel. This suggests that drivers might allow more lateral room for error in overtaking another vehicle in darkness if the lead vehicle displayed a triangular array rather than a pair of tail/brakelights. However, the results of Experiment 4 of the current study provided no support for such a hypothesis. It may be the case that the effect of a substantial changing vertical visual angle on driver behaviour applies to roadside objects to which the driver is not directly attending but not to a car being overtaken, which attracts considerable attention by the driver.

7.3.5 Body-scaling of visual information and criterion of judgement

The simulation used in Experiment 4 was a 1/25 scale representation of the real-world relationship between a driver and the rear lights of another vehicle in darkness. This scaling-down necessitates monocular testing for the same reasons as the experiments on headway change detection.

Therefore it was not appropriate to instruct subjects to say whether or not the target vehicle was coming straight towards them, because they viewed it with their right eye, with the visual result being that a target vehicle heading towards a subject's nose would appear to be travelling slightly to the left side of the subject. Therefore the zero relative trajectory (the collision course) was a trajectory that would take the target vehicle to the center of the subject's right eye.

Assuming that visual information is bodyscaled (Turvey & Carello, 1986), there is a potential limitation to this approach. Passing by an object is a task that calls for perception of an object's changing position relative to the whole body rather than just to the eye. It is possible that subjects might have judged larger relative trajectories as being collision-course ones had the task been to judge the trajectory relative to the body rather than simply relative to the eye. The issue of whether the visual information about relative motion which is received through the eye specifies motion relative to the eye itself or to the whole body is one that remains to be resolved by perceptual psychology.

However, if we consider the difference between the minimum relative trajectory that will not lead to a collision with the eye itself and the one that will not lead to a collision with any part of the body, the difference, in real-world driving terms, is slight. But there is a further problem which concerns body-scaling of information and laboratory simulations of real-world driving.

The real-world driver not only needs to ensure that his/her own body is not on a collision course with the other vehicle, but also has to ensure that his/her car, which is considerably wider than the human body, does not collide with that vehicle. There is some suggestion (Flascher, Shaw, Carello, & Owen, 1989) that "ego-extension" (such as that occurring when we drive a car) is accompanied by appropriate rescaling of affordance information in the optic array. The above authors found a relationship between the width of a car owned by a subject and the subject's judgements of whether the width of an aperture was passible for their car. If drivers therefore 'rescale' the visual world when they get into their car, how representative are the results of the current, laboratory, study of real-world driving? Would drivers in their cars judge greater relative trajectories as collision-course ones as a consequence of having to take the actual width of their car into account?

It is likely that they would, but the extent of the increase (in minimum tolerable relative trajectory) would depend on the side of the car the driver is situated in and also on whether he/she was trying to pass to the left or the right of the lead car. In the present study, the simulation was such that subjects appeared to be either directly approaching or heading to the left side of the target vehicle. If we assume that this represents New Zealand or British drivers, who are positioned in the right side of their vehicle, then the amount of vehicle width that needs to be taken into account is quite small. Thus the laboratory simulation may be considered representative of real-world driving conditions if it is taken to represent drivers positioned in the right side of vehicles who are trying to pass to the left of other vehicles, or (in the case of American or continental driving) drivers positioned in the left-side of vehicles who are trying to pass to the right of other vehicles. In the other two possible situations, however, we would expect drivers to consider larger relative trajectories as safer.

Nevertheless the results of Experiment 4 should be treated with caution because of the possible confounding effects of body-scaling of information in the scaled-down laboratory setting.

7.3.6 Response bias, motivation, and frustration

One disadvantage of the double-staircase method of threshold determination is that it does not provide a measure of response bias. However, a signal detection procedure would have required more trials than was feasible given the number of light configurations requiring examination in Experiment 4.

Motivation may be an important factor in generalising from the results of such laboratory research. It did not really matter to the subjects in the laboratory simulation whether or not they responded correctly, but in the real-world driving situation one might expect a bias towards judging relative trajectories to be collision-course ones. Wolf, Algom, and Lewin (1988), in a study of gap acceptance by drivers, found that drivers were more liberal in gap acceptance in the laboratory than in the field setting, and attributed this to "differences in the respective payoff matrices" (p. 700) (i.e., the cost of errors).

The subjects in Experiment 4 were paid for their participation but nevertheless had to spend a considerable length of time undergoing testing. Subjects seemed to improve with practice, but it could be argued that they were becoming more liberal, or taking more risks, as the experiment went on, perhaps as a result of frustration. The subjects did not show any signs of frustration, but the possibilty exists. Wolf et al. (1988) examined the effect of a low, medium, or high level of frustration on gap acceptance. They found an effect of frustration in the field study, with moderately frustrated subjects adopting a more lenient criterion than lowly or highly frustrated subjects. There was however no such effect in their laboratory study.

7.4 Motorcycle rear lighting

Because Experiments 1(a), 2(a), and 4 included a single-light configuration, the study has some relevance to motorcycle rear lighting.

It was found in Experiments 1(a) and 2(a) that headway change thresholds were higher when there was one 'taillight' than when there were two. This suggests that a change in headway should be harder to detect when the lead vehicle is a motorcycle. Certainly, Mortimer (1972) and Lee (1976) have suggested this. Perhaps motorcycles should be fitted with a pair of brakelights instead of one to improve the headway-change sensitivity of following drivers. However, the results of Experiment 4 indicate that the relative trajectory of a lead vehicle is more easily perceived by the 'overtaking' driver when the lead vehicle displays only one 'taillight'. While placing a single taillight on the rear of cars would be a hazzardous practice for the reasons outlined earlier, it is not dangerous in the case of motorcycles because the motorcycle is not much wider than it's taillight. Therefore the relative trajectory of the single taillight does provide overtaking drivers with very accurate information regarding how safely they are passing a motorcycle.

Therefore there might be an advantage in adding a second taillight for headway maintainence purposes, but adding a second light might make judgements of relative trajectory more difficult. Should a second light be added then?

Basically the answer to this question is no. A second taillight is not needed because the incidence of rear-end collisions involving motorcycles as the lead vehicle is not in fact disproportionate. In 1985[1] and 1986[2] there were only 48 and 31

1,2. From data presented in *Motor Accidents in New Zealand*, Ministry of Transport, 1985, 1986 (respectively) reported incidents in which a motorcycle was the lead vehicle in a rear-end collision on New Zealand roads. The total number of rear-end collisions (according to the same criterion) for all vehicle types was 763 and 801 for the two years respectively. In 1985 then, motorcycles were the lead vehicle in 6.3% of rear-end collisions, and constituted 7.9%[3] of the registered (on-road) motor vehicle population. In 1986, they were the lead vehicle in only 3.9% of rear end collisions, and represented 6.8%[3] of registered on-road motor vehicles. Olson (1989) reports that there is no difference between the involvement rates of cars and motorcycles in collisions with cars for any type of multi-vehicle accident except those in which a car turns across the path of an oncoming motorcycle. For this type of collision, motorcycle-car collisions occur much more frequently than car-car collisions. Thomson (1980a, 1980b) concluded that rear-end collisions involving motorcycles as the lead vehicle are rare in New Zealand.

This may be due to the fact that the very narrow width of motorcycles decreases the base probability of their being struck from behind. It is also easier to go around a motorcycle, so drivers who find themselves closing rapidly on a motorcycle are probably more likely to try to 'go around' than are drivers who are closing on a car. Therefore there does not seem to be any reason why motorcycle rear-lighting arrangements should be altered since these vehicles do not appear to be in any unusual danger of being struck from behind, and a single taillight is probably of sufficient utility to overtaking drivers.

7.5 Suggestions for further research

7.5.1 Headway change detection and alternative rear light configurations

It is possible that the effect found by Mortimer (1972) only occurs when there are other attentional demands on the driver, since he used a distraction task while the present study did not. However, the distraction task he used was somewhat artificial, and perhaps not relevant to real-world driving.

3. The on-road motor vehicle population is intended to mean all registered motor vehicles other than those owned by motor vehicle dealers. The size of these populations is available from the *Official New Zealand Yearbook, 1987/1988.*

Possibly an experiment which employed a different type of distractor would be more relevant to real-world conditions. Rockwell (1972a) has noted that while most fixations are on the lead car in car-following, sober but not drunk drivers also fixate on oncoming traffic. He suggested (Rockwell, 1972b) that such fixations are captured by a movement in the visual periphery which 'attracts' the attention of the eye.

The apparatus used in the current study could be modified to simulate such distracting effects of oncoming traffic. A conveyor belt of black felt material for example could be installed to run parallel to the rails on which the target vehicle runs. By placing pairs of small white lights on this belt at varying intervals and varying the speed of the belt, the simulation of oncoming nighttime traffic could be achieved. Involuntary fixations on these lights would make the primary task more difficult, and consequently bring out any differential effects of various light configurations on the target vehicle.

Given that there is a possibility that the triangular or square light array might only be more effective than the pair when fixations on the lights are relatively short, an experiment in which both exposure durations and light configurations were varied could provide useful information on this possibility.

Although differences did not emerge in the present study as regards detection of headway change, it is possible that differences might occur if the task was of a different nature. It might be the case that drivers do not find changes in distance to a triangular array easier to detect, but do find it easier to to actually maintain a given headway behind a lead vehicle if that vehicle displays a triangle rather than a pair of taillights. This possibility could be examined by repeating the type of car-following experiment carried out by Bierley (1963), but this time in darkness, without the aiding displays, and employing on the target car the various light configurations used in the current study. Lower variance in headway during a trial might be found when a triangle rather than a pair of taillights is displayed.

Another area of interest concerns time-to-collision judgements. Let us assume, for example, that subjects were exposed to the apparatus used in Experiments 1(a)-2(b) and, given a short glimpse of the approaching target vehicle, were required to indicate, in a manner similar to the subjects of McLeod and Ross (1983) and others, when they thought the target vehicle would reach them. It is possible that even though the triangular light configurations did not enable subjects to be more sensitive in detecting changes in headway, such light configurations might permit greater accuracy in estimating time-to-collision. Of course, since subjects in such studies generally underestimate time-to-collision, such an effect might not be considered an improvement if people perceive time-to-collision as being longer as a consequence of changes to taillight configurations.

The results of Experiment 1(b) suggested a possible effect of the positional height of the top light in triangular arrays. This is an aspect worthy of future attention, especially since high-level brakelights are becoming increasingly common and users are varying the positional height of these lights considerably. The effect of the shape of the triangle of lights produced should therefore continue to be considered in possible future experiments.

7.5.2 Relative trajectory discrimination and alternative rear light configurations

The results of Experiment 4 have limited generalisability because the subject did not have to consider own vehicle width in deciding whether or not she was on a collision course with the set of red lights. An obvious way to overcome such a problem would be to set up a field test in darkness whereby subjects were driven as passengers toward a stationary car showing activated tail/brakelights. The subject's car would either approach directly, or indirectly so as to pass either to the left or right of the target. The subject would be given a glimpse of the target car during the approach and would be required to judge whether or not a collision would occur. As well as manipulating the actual relative trajectory and the configuration of red lights on the other vehicle, an experimenter would also look for differences in judgements depending on whether the indirect approaches were to the left or right of the target vehicle; given that the subject would be sitting in the left side of his/her car, it would be expected that smaller relative trajectories would be considered safe for trajectories leading to the right of the target car, since there is less car width to be taken into consideration by the subject when this is the case.

Another possibility is to conduct an experiment similar to that run by Micheals and Cozan (1963). In this case, however, the displacing object would actually be in the subject's line of travel. The subject would drive the car, and would be instructed to 'overtake' the obstructing object, actually a parked car displaying one of the various configurations of taillights, by passing either to the left or right of it. However, the subject would be instructed to do this with as little deviation as possible from his/her line of travel, and would perhaps be provided with some incentive to do so. Lateral displacement in 'overtaking' would thus be the variable of interest, as one might expect this to be different when the obstructing vehicle displayed a triangle rather than a pair of lights. A fixed approach/passing speed would be enforced, since Micheals and Cozan (1963) found lateral displacement to vary with approach speed. It might also be expected that a driver positioned in the right side of his/her vehicle will deviate less when passing to the left side of the target than when passing to the right side of the target.

7.6 Summary of experimental findings

This thesis began with two questions. Both concerned the effect of various tail/brakelight configurations on the perceptual abilities of following drivers. The scenario of interest was that in which, in darkness, the taillights of the lead car are activated, or the brakelights have for some reason already been activated for some time. One question asked whether a light configuration which added a vertical visual angular component to the existing horizontal one made detection of a change of headway easier. The other asked whether such a light configuration would make the distinction between collision-course and non-collision course trajectories more accurately detected. Based on the results of the experiments conducted, the short answer to both of these questions is no, although in Experiment 1(b) there seemed to be some effect of the amount of vertical visual angle in the triangular light arrays, depending on initial distance, when triangular arrays were compared amongst themselves. However, a pair of lights appears to be equally effective for these purposes.

The expectation that a pair of lights should be better than a single light for motion detection purposes was supported by the experiments, but a less expected finding was that relative trajectory of a light configuration was easier to judge when there was only one light than when there were two.

In the headway-change detection experiments, detectable distance change increased with initial distance, as expected. However, the direction of relative motion by the target vehicle had no effect.

The auxiliary, center-high mounted brakelight has been shown in previous research to be effective in reducing rear-end collisions, but the current experiments do not provide any consistent evidence to suggest that this effectiveness would seem to arise in any part, large or small, from the triangularity of the array of brakelights that it contributes to.

However, Mortimer (1972) did find that a triangular array was more effective than a pair of lights in signalling change in intervehicle distance. A number of conditions in his experiments differed from conditions in the current experiments, and these differences may explain why the same effect was not found in the current study. Certainly, early studies on differing rear reflector shapes (Hoppe & Lauer, 1951; Potter, 1961) support Mortimer's findings. It is noteworthy in this respect that an interaction between light configuration and initial distance was found in Experiment 1(b), suggesting that altering the shape of the triangle of lights was in some way affecting motion perception.

Therefore the hypothesis may still be valid, and a number of experiments which might better test it have been proposed in the previous section. But a pertinent question is: does the hypothesis warrant further attention?

7.7 Should further research be done?

7.7.1 Utility of possible effects

Many would argue that the differences found by Mortimer were slight, and they might consider the results of Potter (1961) in the same way. But it is often the case that the difference between a non-collision and a collision is only a few feet or less. Major disturbances in traffic flow may often originate from minor velocity changes by vehicles which were not noticed early enough by following drivers. Even though such disturbances may not cause collisions in the traffic stream, they may contribute to traffic stoppages, slower flow, higher fuel usage and carbon monoxide levels, and increased incidence of motor failure. If a certain taillight configuration offers only slightly better sensitivity to headway change, it may still contribute to smoother traffic flow.

The high-level brakelight has proved an effective collision-prevention measure, but there are many situations in which closure is occurring and the lead car has not braked; when two cars are accelerating and the lead one is less powerful, when a more powerful car is travelling behind another car on an incline, when the lead car is coasting for some reason, when the lead driver is employing 'gearbox braking', if the lead car's engine has stalled, or a gear change has been bungled. Such situations are common on the road and may contribute to traffic flow disturbances if not collisions.

7.7.2 Has research done so far been successful?

Such possibilities as triangular taillight arrays should continue to receive attention for other reasons as well. One of these is the danger that existing safety measures will become less effective with time and changes to the driver and motor vehicle populations. How likely is this?

Thomson (1984) raised the possibility that a 'novelty' effect might be associated with the center-high mounted brakelight. He himself concluded that such an explanation for the effectiveness of these lights was unlikely since Malone et al. (1978: cited by Thomson, 1984) found that the system of two high-level brakelights, although equally as 'novel', was no more effective than the traditional system. Furthermore, he argued that, rather than the effectiveness disappearing as such lights become more common, effectiveness should increase as numbers of vehicles equipped with them increase and "the message to the following driver is better learnt" (p. 139).

Rumar (1980) examined the effectiveness of daytime running lights in improving vehicle conspicuity. While arguing for the effectiveness of these lights, he raises the possibility that vehicles not carrying the lights will become less conspicuous through a contrast phenomenon. The New Zealand Ministry of Transport has expressed concern that the safety effect of headlight use by motorcyclists in daylight would be lost if other vehicles carried day running lights (Road Safety Review, 1989). Is it possible that cars not carrying auxiliary high-level brakelights will become increasingly involved in rear-end collisions as the number of cars carrying such lights increases? Will drivers come to learn to respond to high level brakelights so well that they respond less effectively to braking by vehicles not carrying such lights?

In addition to possible 'novelty' and 'contrast' effects which might be associated with emerging accident prevention measures, there is also the possibility that drivers might be getting 'lazier' or more complacent as driving is made easier and safer for them through changes to the road or vehicles. Neither brakelights or turn indicators were compulsory in Britain in 1967 when Cohen and Preston (1968) carried out a survey of long distance lorry drivers using the main British motorways. They found that eight out of nine day drivers and half of the night drivers did not have direction indicators on their vehicles. Also of interest was the system of signals employed by the truck drivers to assist each other in overtaking, a mildly cryptic system of headlight and taillight flashes apparently of great meaning to those 'in the know'. The trucks of those times also required greater handling effort of their drivers than the truck of the 1980s. The modern truck carries brake and turn indicators and features a stronger motor, power steering, air brakes, and a more user-friendly gearbox, to name but a few improvements. Similar improvements to private cars have characterised recent decades. But are drivers actually getting better at avoiding accidents as a result of these improvements, or are the improvements being compromised by declining driver input? One way to test this assertion and the 'novelty' hypothesis might be to look at accident and road death statistics for recent decades to see if or how they have changed through the decades in which accident prevention research and legislation has occurred.

In New Zealand, the number of road deaths occurring in proportion to the number of vehicles registered is falling and, according to the D.S.I.R. (Road Safety Review, 1989), has been falling for several decades. In 1988 there were 3.3 road deaths per 10,000 vehicles, compared to 3.8 in 1987. However in 1936 there were 8.6 deaths per 10,000 vehicles. Toomath (1975), in an analysis of New Zealand road accident trends between 1953 and 1973, found that figure to be fairly constant for the period, being 6.1 in 1953 and 5.9 in 1973, although dipping slightly to 4.4 in the mid 1960s. Reference to the 1986 Ministry of Transport statement on road accidents gives the numbers of road deaths and registered vehicles for the years following Toomath's study. The period of 1974 to 1986 shows a decline in road deaths per 10,000 vehicles, down to 3.7 in 1985 and 1986.

If the road death rate is expressed in proportion to actual population (per 100,000 people), then a different picture emerges. Toomath (1975) found a doubling of deaths per 100,000 people between 1953 and 1973, rising from 15.1 to 27.9. Between 1974 and 1986 a different trend emerges. Road deaths per 100,000 people declined from 21.8 in 1974 to 17.5 in 1979. A further period of improvement occured in the early 1980s, but was followed by a rise to 22.5 for 1985 and 23.1 for 1986.

Turning to overseas data, Leeming (1969) found a steady rise in road deaths per million inhabitants in England and Wales, from 96 in 1946 to 135 in 1963. Baker (1971), in an analysis of U.S. accident data for the period of 1913-1968, found the road death rate (per 100,000 people) to increase quite consistently over the period, from 6.8 to 27.6. But the death rate per 10,000 vehicles declined just as uniformly over the same period, from 23.1 to 5.41.

The most recent and comprehensive road accident statistics have been assembled by Hutchinson (1987). Table 1.5 (p. 8) of that publication provides data on the road death rates (per 100,000 people) for 1980 and 1984 for 28 countries including New Zealand. Twenty-one of these showed a decrease in the road death rate (regardless of age) and one showed no change.

Therefore the road death rate as a proportion of the number of registered vehicles continues to decline as it has done for many years. Until recent years, the road deaths seemed to be increasing in proportion to the population, but this trend is probably due to the fact that the proportion of people involved in using private road vehicles has been increasing over the decades. Presumably this involvement has reached a plateau and we are now seeing a decrease in death rates proportional to population size. In terms of road deaths alone then, the road environment would seem to be becoming safer.

This of course does not neccessarily mean that drivers are performing better; it may be the case that improved roads, safer-in-impact cars and improved emergency and medical services have increased one's chances of surviving an automobile accident. What is therefore an important question is whether the number of road accidents is actually decreasing.

Toomath (1975) found that the rate of road accidents (per 100,000 people) increased markedly, from 273.2 in 1953 to 514.4 in 1973. Ministry of Transport statistics[4] for the subsequent period show a declining trend, from 456 accidents per 100,000 people in 1974 to 307 in 1979. This rate stayed about the same until a new rise began in 1984. However, if the accident rate is expressed in proportion to the number of registered vehicles, we find a different trend. Toomath found this rate to be fairly constant for the 1953-1973 period, being approximately 110 per 10,000 vehicles. However, this accident rate has since declined, from 93 in 1974 to 56.1 in 1979, the rate then staying at about this amount before beginning to rise slightly in the mid 1980s.

The road death rate is coming down. In the late 1970s and early 1980s the wider road accident rate also showed a decreasing trend, and even after a slight rise in the

4. Derived from data presented in *Motor Accidents in New Zealand*, Ministry of Transport, 1985

late 1980s is still lower than in the early 1970s. It would seem therefore that the great amount of research aimed at improving the safety of roads, vehicles, and drivers is succeeding. This would suggest that 'novelty' explanations for the success of newly introduced accident prevention measures are incorrect, and that drivers are not becoming more complacent as the driving environment is made safer for them. The possible 'contrast' problem (increased involvement in accidents of vehicles not carrying running lights, high-level brakelights etc.) is not resolved so easily, and is one potential problem which is worthy of study over the next few years.

7.7.3 Road safety for the future

If safety measures, such as high-level brakelights and day running lights, are proving successful and are likely to pay further safety dividends as their use becomes more widespread, is there any point in continuing to research such possibilities as those which this thesis has examined? It could be argued that what has been achieved and what are the more promising lines of research should be sufficient, and that time and resources are wasted in the pursuit of ideas that seem to show little promise or 'payoff' potential.

There are two reasons why such ideas as those proposed in this thesis should continue to be attended to. The first is concerned with the distinction between factors that contribute to accidents and factors that contribute to safe driving; some potential changes to vehicle rear lighting (to take an example) may not be 'accident-preventors' (as high-level brakelights are) but 'safe-driving enhancers'. It might be the case for example that a triangular tail (presence) light array might make a small improvement to a following driver's ability to maintain a headway. As such it would not prevent accidents but would enhance normal driving with the effect that drivers are less likely to get themselves into potential-accident situations. Such an effect of triangular light arrays was not suggested by the current study but was found by Mortimer (1972) under different conditions. Often in safety research there is disagreement over whether we should ask why (or under what conditions) accidents sometimes happen or why they usually don't happen. Research of the type presented in this thesis perhaps falls into the second category. But this category is often neglected because of socioeconomic pressures to stop the accidents.

The second reason why such ideas should not be completely shelved away is that the driving environment continues to change. The average age of the driving population will have risen dramatically by the beginning of next century, and older drivers may respond differently to visual information. It is difficult to believe that average driving speeds will not increase in the next few years, and vehicle usage patterns may well change as lifestyles change. Increasing road traffic in developing countries may reveal new hazzards or potentials for safer driving. Changing interiors, control systems, and overall dimensions of motor vehicles may mean that different perceptual-motor systems will characterise driving behaviour of the future. While high-speed rail transport is being developed in Europe and Japan, the absence of such development in the United States is leaving that country with a worsening traffic congestion problem (Rosen, 1989). Such centres as Auckland may expect similar problems. Thus, for many reasons, driving in 15 to 20 years' time may be a very different experience to what it is now. A modification to rear-vehicle lighting that has no effect now may prove to have some usefulness in the future. Hence, are therefore several reasons why it is important to continue to review some ideas that may not have been successful in their time as well as to update road safety research.

7.8 Conclusion

This thesis has been concerned with two particular aspects of vehicle rear lighting and car-following behaviour. Two broad predictions were made, for which little empirical support was found. That such effects were not found is as equally important as would be the case if the predicted effect had been found, since it is just as important to find factors which do not seem affect a certain behaviour as it is to find those which do.

One of these predictions has a history of research that has provided support for it. The fact that experiments previously done provide support for the hypothesis suggests that, under certain conditions, it may be valid. Therefore it may be fruitful to find out precisely what those conditions are. The driving environment continues to change, and such conditions may one day be the norm rather than the exception.

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8. Appendices

Appendix 1: Velocity and momentum patterns for the target vehicle

1. Motion properties of the target vehicle

The target vehicle consisted of a model railway wagon (HO guage), which carried the light configurations, attached to an electric model locomotive. Electric model locomotives are characterised by their rapid acceleration and deceleration, which results from the motor and gear system, and were thus ideal for the current experiment. However, it was necessary to gain some information on the aceleration, running speed, and deceleration behaviour of this target vehicle, so that the behaviour of the target vehicle could be considered in relation to the behaviour of the subject observing it.

2. Running Speed of Target Vehicle

The running speed of the model train which comprised the target vehicle was obtained by a series of stopwatch trials. The train was started from a point beyond point A which was far enough away that the train would have reached full speed on crossing point A. The train was timed between point A and point B, which was 62.5 cm further down the track.

24 trials were done, 12 for forward speed (corresponding to movement toward a subject) and 12 for reverse speed. The mean forward running speed was 31.3 cm/sec and the mean reverse running speed was 30 cm/sec. Thus the running speed was taken as approximately 30 cm/sec.

3. Other Time Trials

Trials were also run from standing starts so as to ascertain how much difference the acceleration phase would make to the overall velocity over the same distance as that used above.

Again 12 trials were run for each direction of travel, over the same 62.5 cm distance. The mean forward speed was 28.4 cm/sec and the mean reversing speed was 26 cm/sec.

Similar trials, again 12 in each direction, were run over a distance of 114.8 cm. The mean forward and reverse speeds were both 28.7 cm/sec.

Overall the time trials suggest no difference in speed attributable to direction which is of note, except possibly in the case of the short distance from a standing start, where there may be a small difference between directions of travel in rate of acceleration.

4. Post-response Travel By the Target Vehicle: Manual Testing

In an effort to try and determine how far the train continues to travel after the power has been cut, the train was started 5, 10, 20, or 30 cm back from a point on the rails. As it crossed that point, the power was cut. There were 10 trials for each of these 'run-up' distances for each direction, producing a total of 80 trials.

Figure A1 shows the distances travelled by the train after the power was cut. In the case of the forward travel, post-response distance travelled seems to continue to increase with the amount of powered travel, while in the reverse travel case, the post-response distance seems to peak with a run-up of 10 cm. This is surprising in view of the stopwatch trials which suggested that the train took longer to attain full speed when travelling in reverse. It seems from the data in Figure A1 that the train takes longer to build up momentum when running forward (noting the basic similarity between directions of travel at the 30 cm run-up). This may be because the locomotive is pushing the wagon carrying the light apparatus when running forward but is pulling it when running in reverse.

The method used to measure this post-response travel by the target vehicle was however somewhat crude. A more refined measuring system was thus then tried.

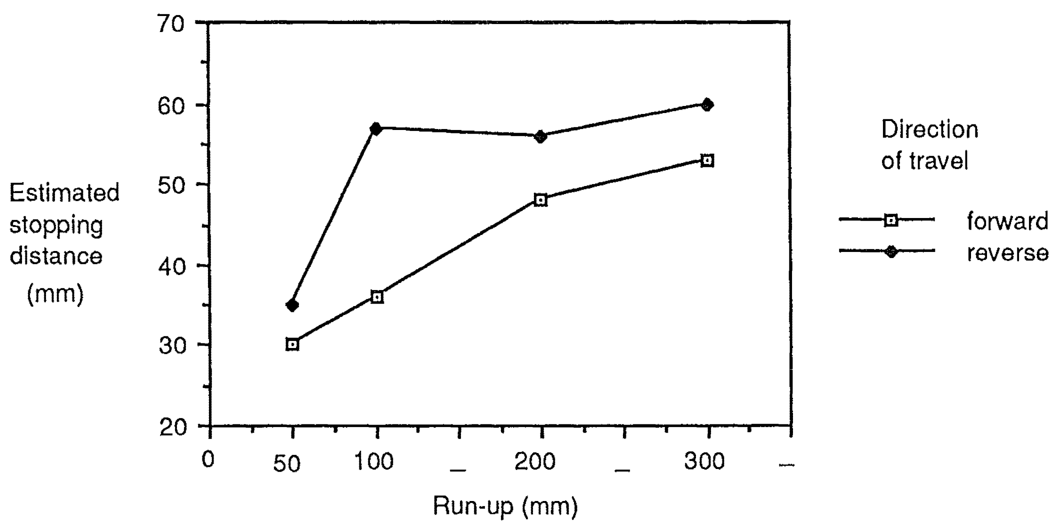

Figure A1: Target vehicle stopping distance by run-up distance

5. Post-response Travel and acceleration by the Target Vehicle: Ticker-timer Testing

5.1 Method

A Modernage ticker-timer (12V AC, 50 Hz) was placed on the rails so that paper tape attached to the target vehicle could be run through it. Unfortunately the paper tape induced a noticable depreciation of running speed, reducing it to 22.3 cm/sec for forward travel and 19.5 cm/sec for reverse travel. However this meant that the acceleration phase would probably be longer than normal, so a conservative estimate of distance taken to reach running speed could be made on the basis of these results.

5.2 Reverse acceleration and momentum.

The train was started up, run for some distance, and allowed to come to a halt as it normally would. This was done a number of times and the ends of the tapes were then analysed, working from the end to the point where velocity had clearly stopped increasing.

The acceleration trend for reverse travel is shown in Figure A2, which shows the distance travelled in each 0.1 second interval. It is evident from these graphs that most of the acceleration had been achieved by the time the train had travelled just 5.7 cm. Mild increments after that may be attributed to the retardive effect of the ticker-tape and are unlikely to be discernable to the observer anyway.

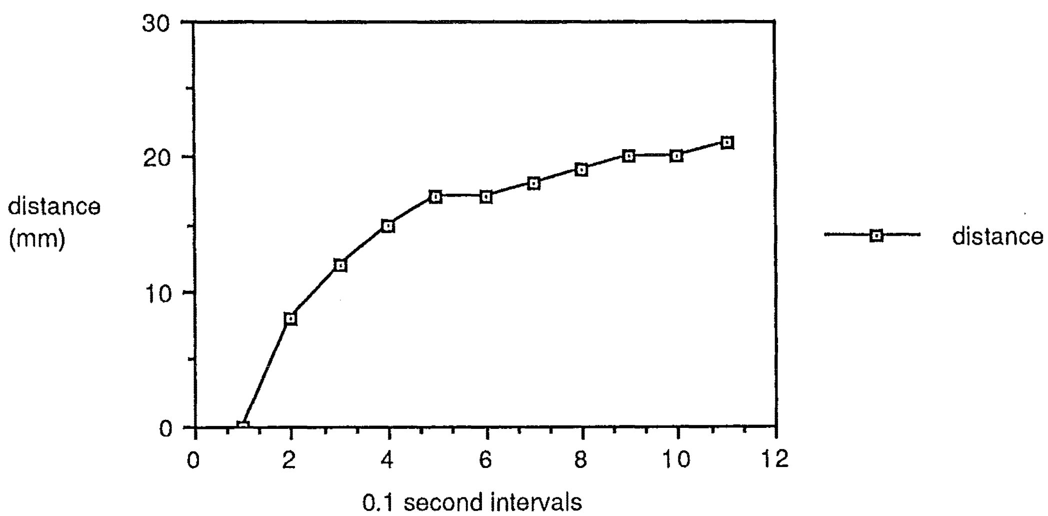

Figure A2: Distance moved in 0.1 second intervals during acceleration in reverse.

The distance required to stop is shown by figures A3 and A4 . It can be seen from these graphs that the train stops within 2-3 cm of starting to slow down. Figure A3 shows distance travelled in 0.1 second intervals and Figure A4 shows distance travelled in 0.02 second intervals. We can be certain that the point at which velocity begins to decrease is the point where the power was cut, because the wheels of the locomotive jam when power is lost.

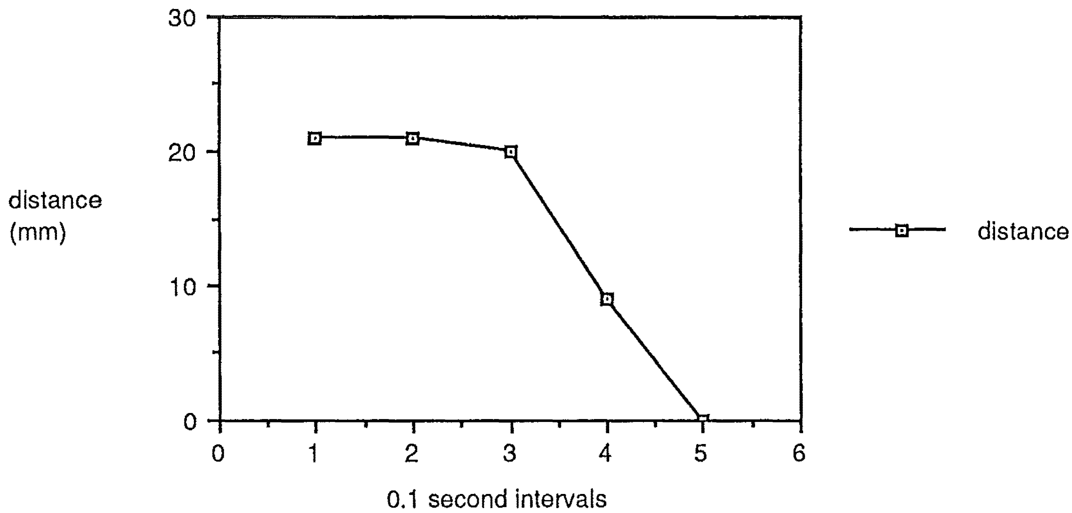

Figure A3: Distance change in 0.1 second intervals for decleration in reverse.

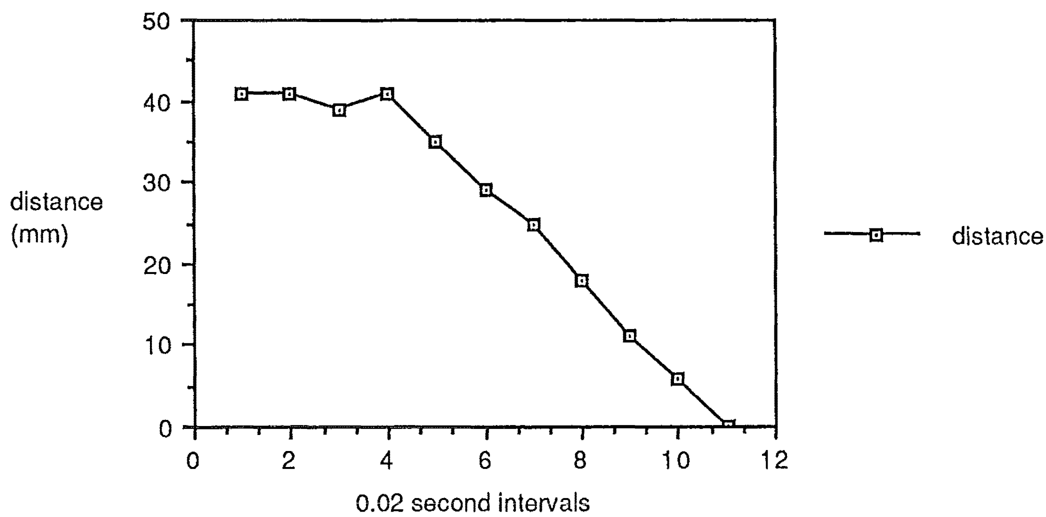

Figure A4: Distance change in 0.02 second intervals for reverse deceleration

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We can conclude from these measures that, under the retardive effect of the attached ticker-tape, the train, when travelling in reverse, travels about 5-7 cm to reach almost full-speed and has a stopping distance of about 2-3 cm, although the stopping distance is probably about 50% greater without the ticker-tape attached (which reduces train speed by 30%) so is probably closer to 3-4 cm.

5.3 Forward acceleration and momentum

The same procedure as above was repeated for forward travel by the train. It is evident from Figure A5 that full speed had mostly been reached after a distance of 6cm. Figure A6 shows the deceleration trend over 0.02 second intervals. Stopping distance appears to be about 1.5-2cm with the retardive effect of the ticker-tape, and thus probably 2.5-3.5cm without the retardive effect of the ticker-tape.

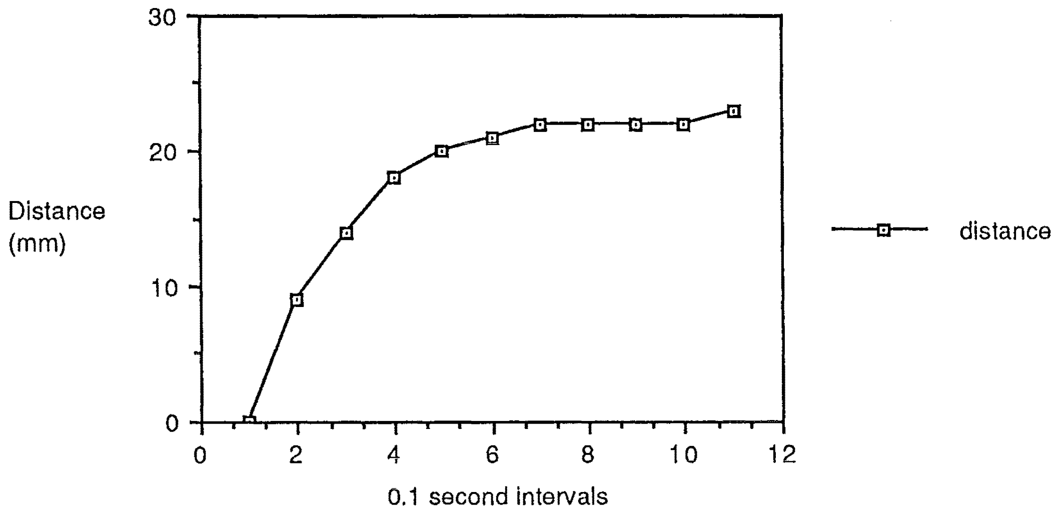


Figure A5: Distance travelled in 0.1 second intervals for forward acceleration.

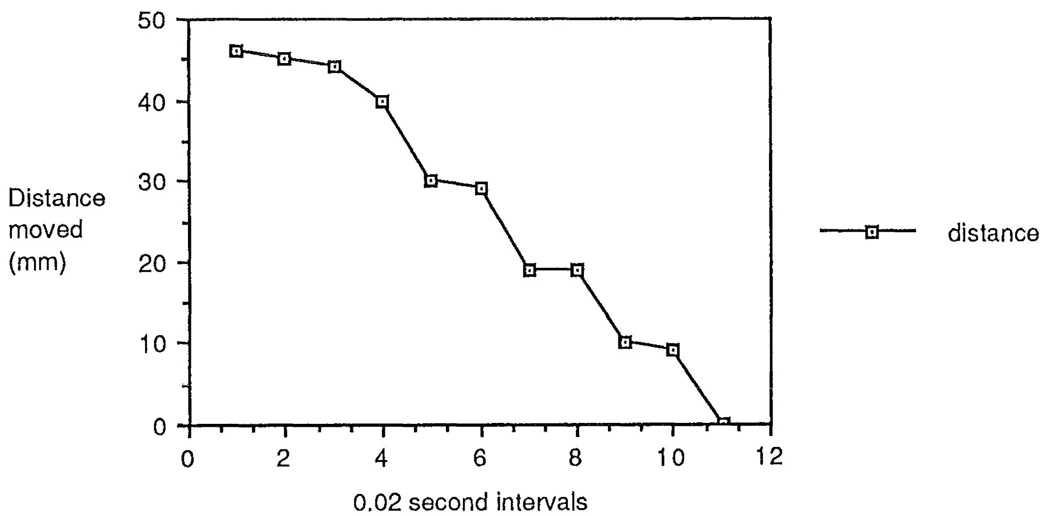


Figure A6: Distance moved in 0.02 second intervals for forward deceleration.

The results of these ticker-tape tests suggest that the method described in section 3 of this appendix may have featured biases arising from experimenter judgement in cutting the power supply at the right point in time.

8.6 Key Points

The full running speed of the train is about 30 cm/second. Running in reverse, it travels about 5-7cm to reach most of it's full speed, and about 3-4cm to stop. Running forward, it travels about 6cm to reach full speed and 2.5-3.5cm to stop.

Therefore, for experiments 1(a)-2(b), an amount of 3cm was deducted from the distance changes measured to give an estimate of the minimum detectable distance change.

Appendix 2

Interaction F-values, degrees of freedom, and levels of significance for Experiment 2(b).

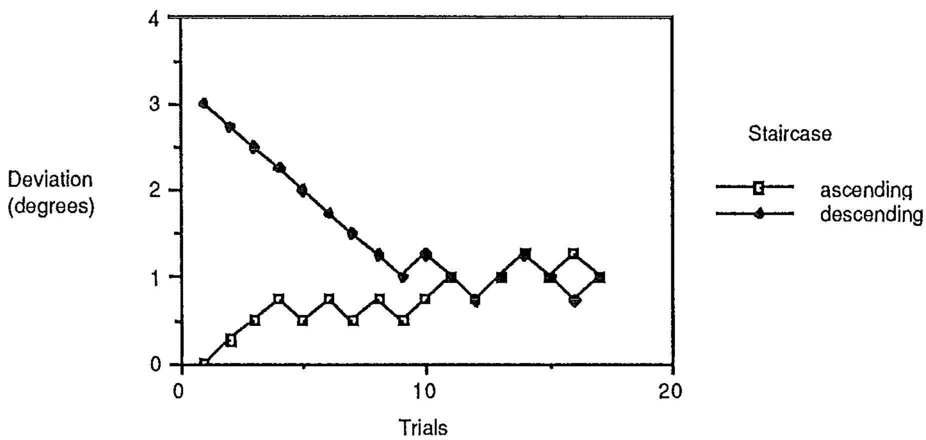
Interaction	F	d.f.	significance
sex x distance	.002	1,8	.965
sex x configuration	.177	3,24	.911
sex x direction	.035	1,8	.857
distance x configuration	.560	3,24	.646
distance x direction	.188	1,8	.676
configuration x direction	1.939	3,24	.150
sex x distance x configuration	.238	3,24	.869
sex x distance x direction	.035	1,8	.857
sex x configuration x direction	.445	3,24	.723
dist. x configuration x direction	.311	3,24	.817
sex x dist x config x direction	.147	3,24	.931

Appendix 3

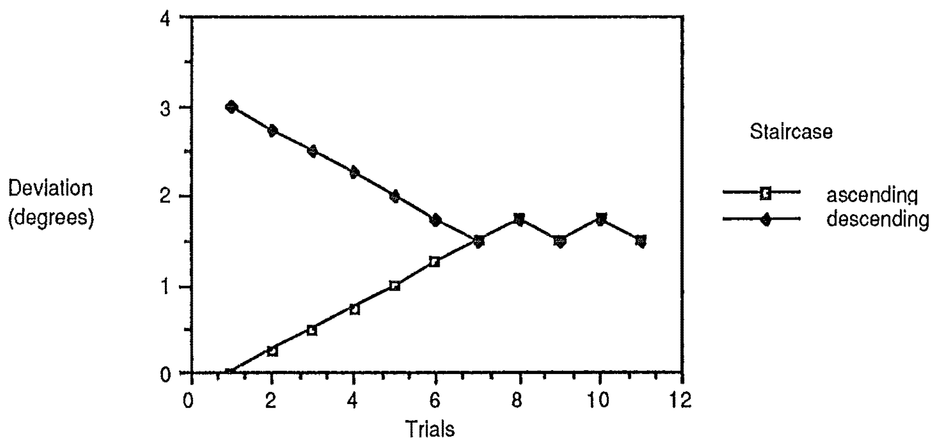
Plots for all double staircases in Experiment 4

(Plots not found here are to be found in Chapter 6)

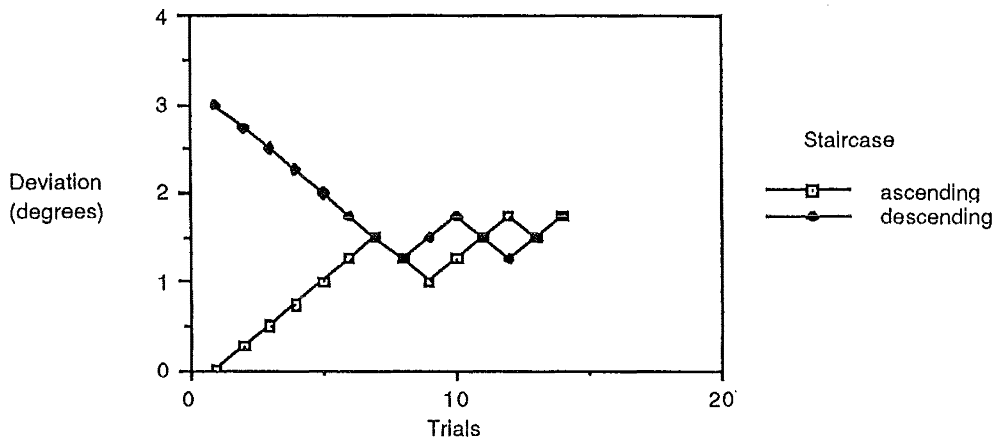
Figures A7-A12: Threshold patterns for Subject 1. (Order of configuration testing: A B C E D F)



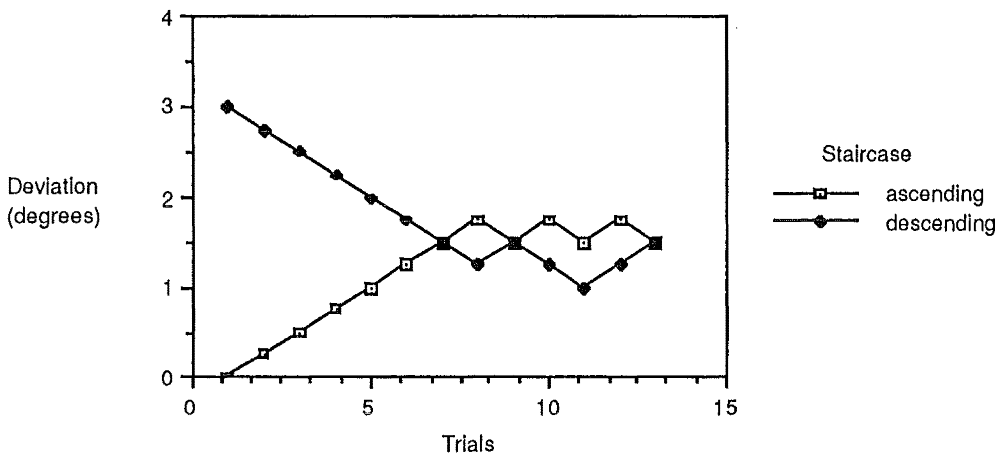
A7: Configuration A



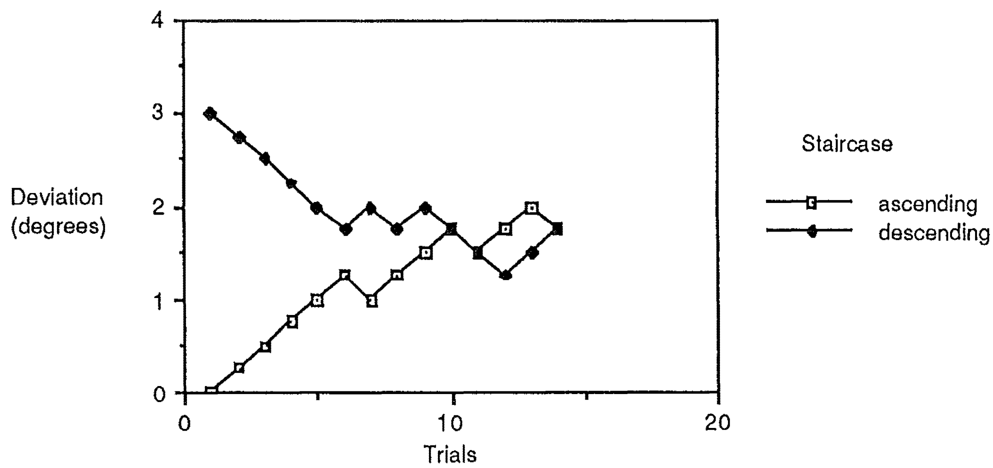
A8: Configuration B



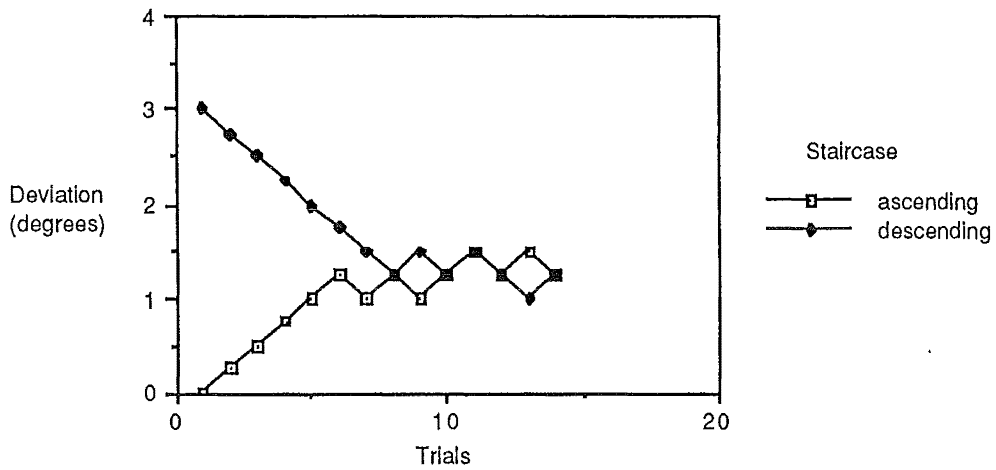
A9: Configuration C



A10: Configuration D



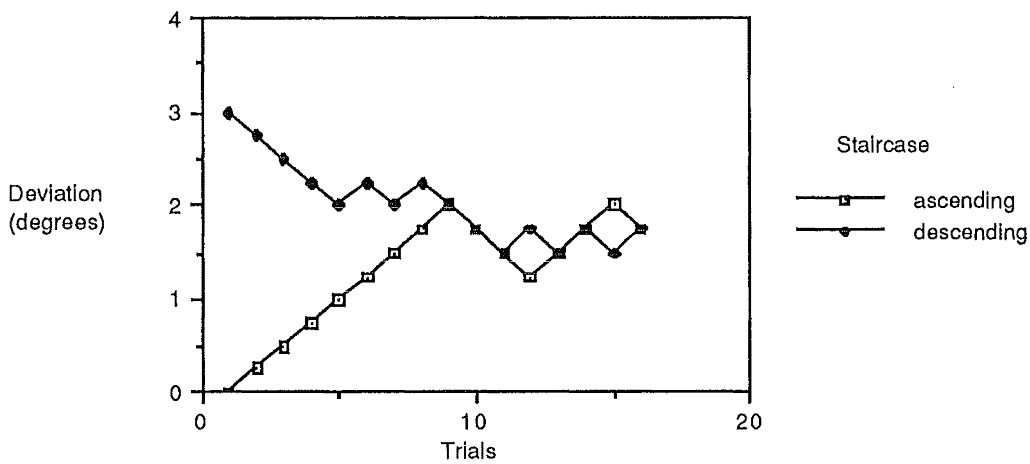
A11: Configuration E



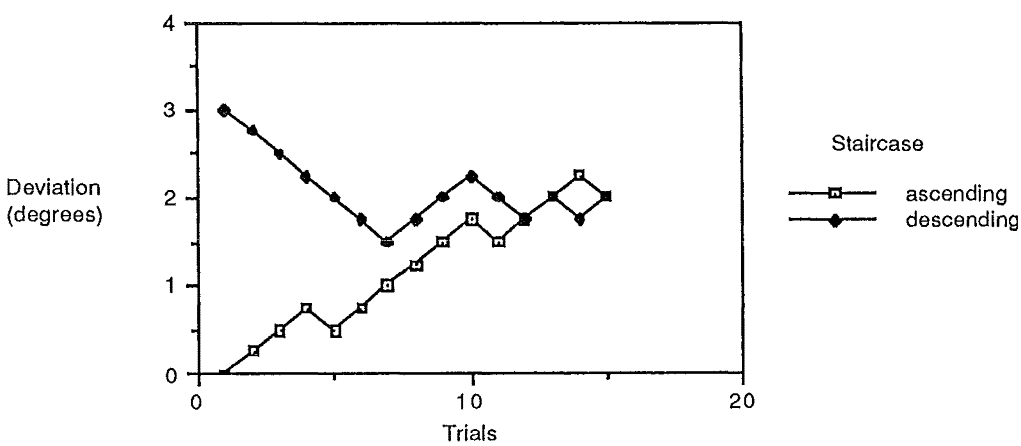
A12: Configuration F

Figures A13-A18: Threshold patterns for Subject 2.

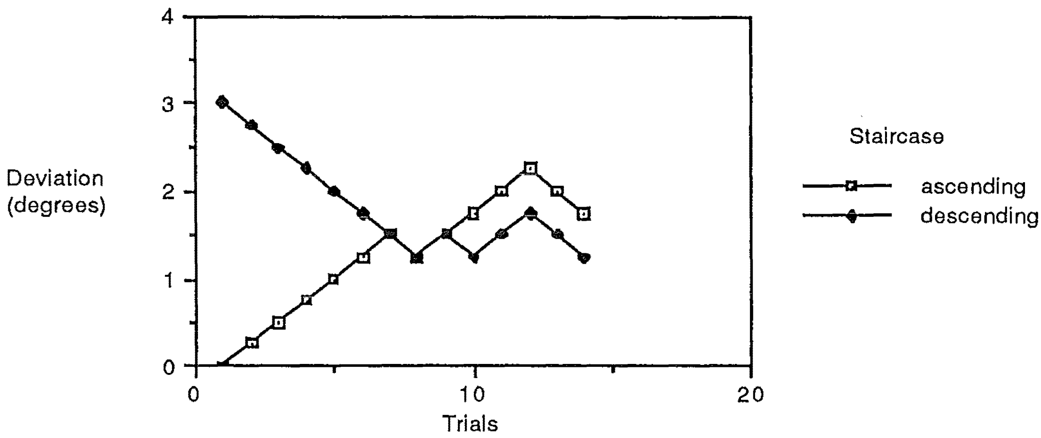
(Order of testing: A B C E D F)



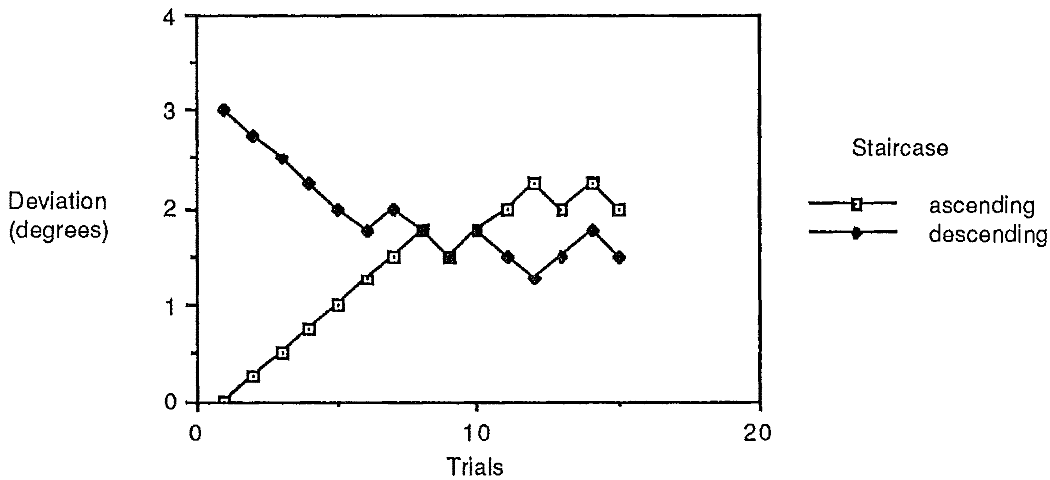
A13: Configuration A



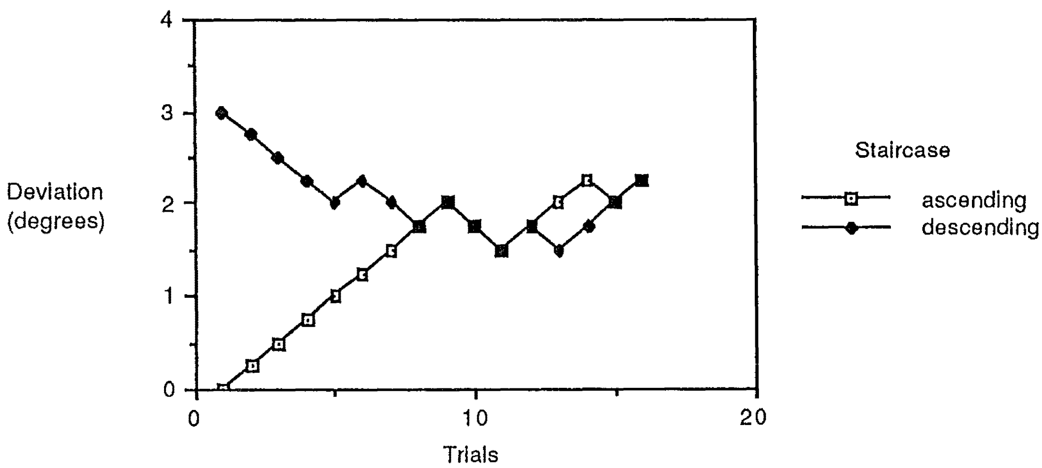
A14: Configuration B



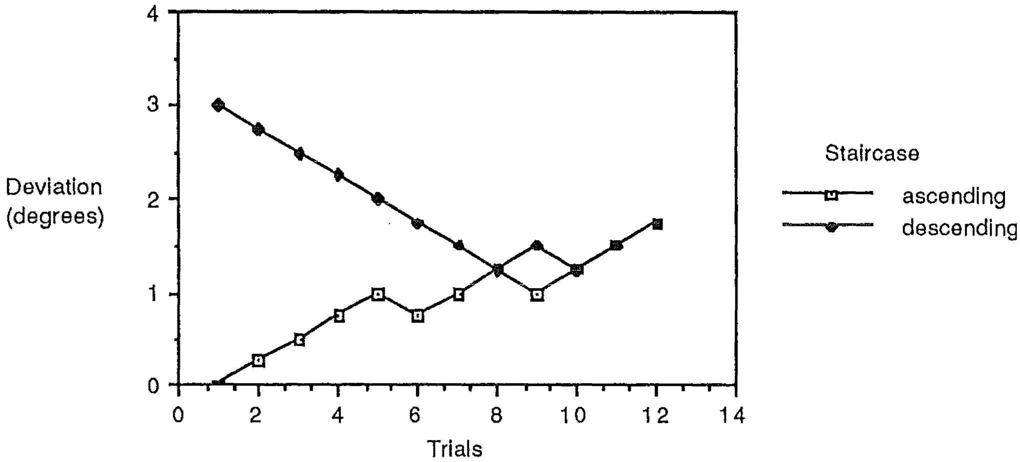
A15: Configuration C



A16: Configuration D

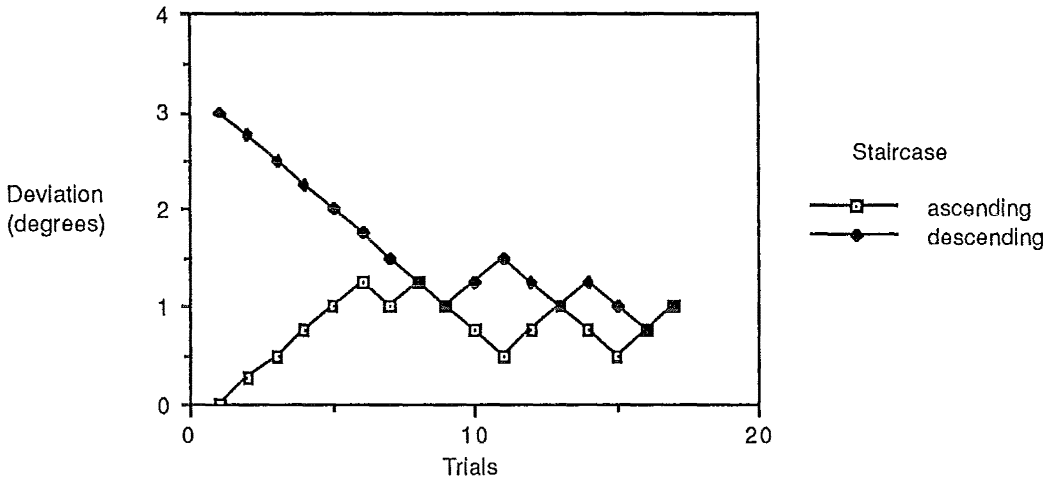


A17: Configuration E

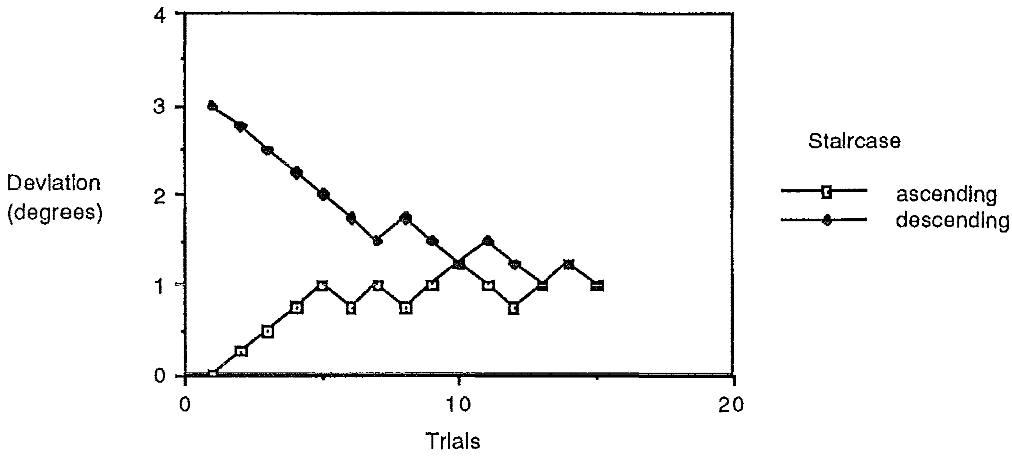


A18: Configuration F

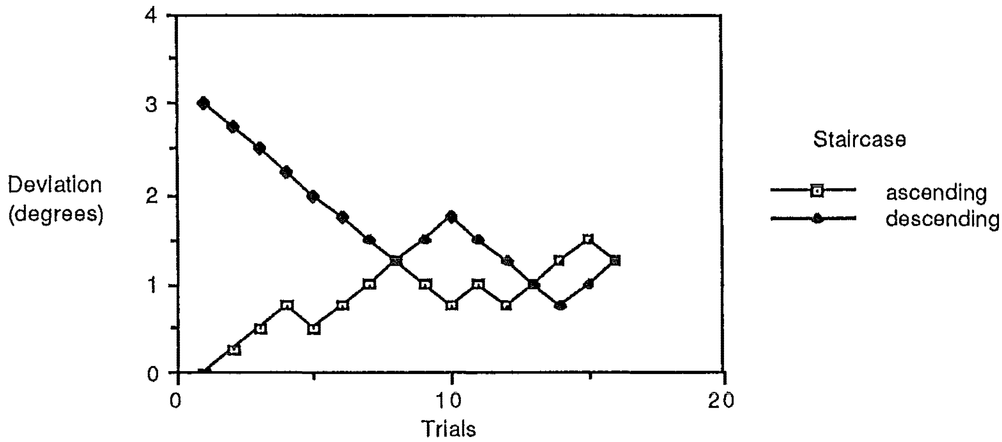
Figures A19-A22: Threshold Pattterns for subject 3 (Order of configuration testing: F D E C B A). (Plots for Configurations A and B to be found in Chapter 6)



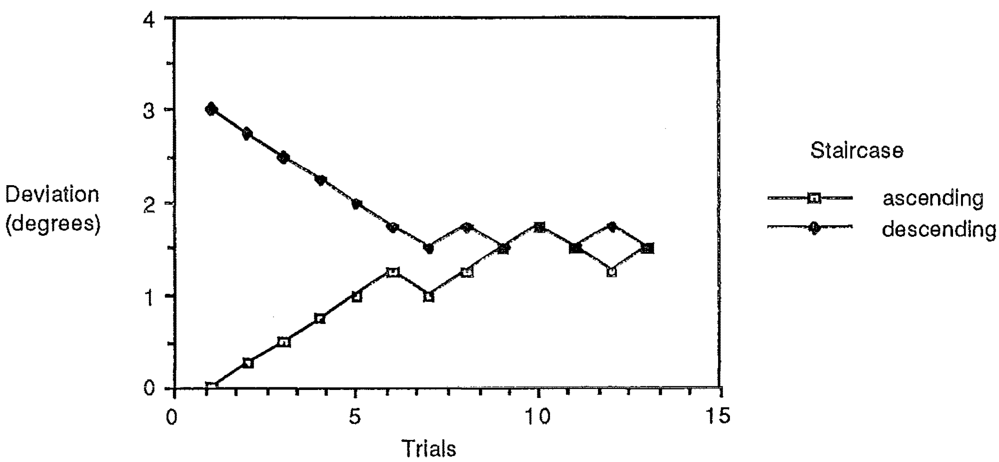
A19: Configuration C



A20: Configuration D

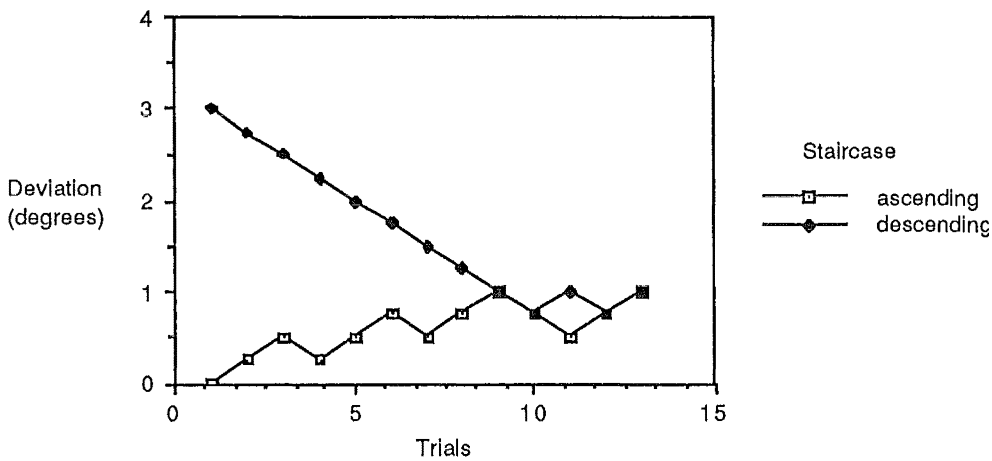


A21: Configuration E

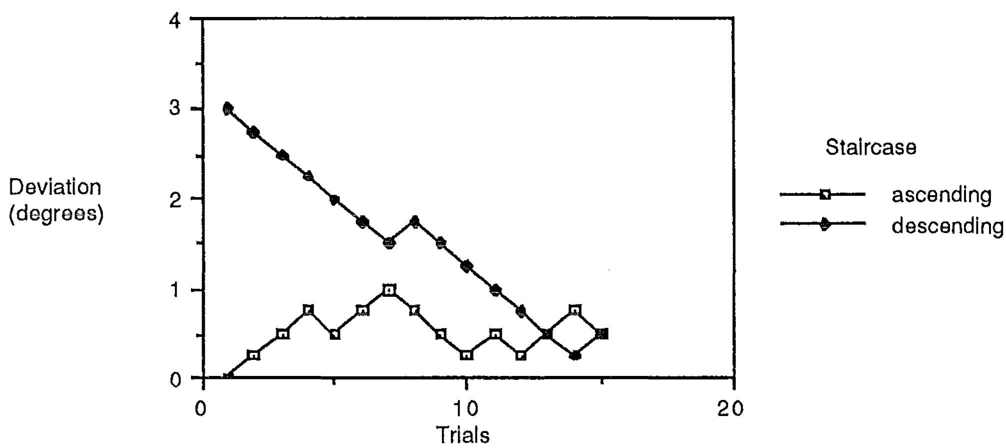


A22: Configuration F

Figures A23-A26: Threshold patterns for Subject 4 (Order of configuration testing: F D E C B A) (Plots for Configurations A and E to be found in Chapter 6)



A23: Configuration B



A24: Configuration C